MATHEMATICAL DRAWING INSTRUMENTS

AND

HOW TO USE THEM

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"Drawing is the A B C of the architect, engineer, and surveyor."

SIR ISAMBARD BRUNEL.

"Drawing supplies us with a power whereby long descriptions and pages of writing are at once superseded, and thus it is a condensed shorthand as well as a universal language."

R. REDGRAVE, R.A.

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AND

HOW TO USE THEM.

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BY

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SECOND EDITION.

APPROVED BY THE SCIENCE AND ART DEPARTMENT.

NEW YORK:

W. T. COMSTOCK,

194 BROADWAY.

1882.

INTRODUCTION.

The use of mathematical instruments enters so largely into various kinds of technical drawing, that some few suggestions as to their employment cannot but be of service to many who find themselves for the first time in their lives the possessors of a box of drawing instruments, and who therefore have all their experience yet to learn. Having for many years been engaged in teaching the use of such things, and thereby become acquainted with the difficulties of the novice, we would desire to give all such the benefit of our own experience, and to smooth their path before them as far as may be possible.

The student who provides his own things is at once met on the very threshold by a difficulty—the choice of a suitable box of instruments. He sees in the shop-windows a card of things marked "one shilling the set;" and, on the other

hand, in consulting the catalogue of a first-class maker, he finds that even twenty guineas would not buy some of the sets enumerated with such tempting richness of detail. Somewhere between these extremes is the very thing he wants, but where the happy mean may be is a mystery to him.

It will be noticed that we assign the true position of the hoped-for box somewhere between the extremes; for we would at once hasten to say that few things are so dear as cheap instruments. The legitimate difficulties of drawing with instruments are sufficiently great to the beginner without complicating them by the introduction of pens that will not mark, screws that will not turn, and all the other troubles that assail any one rash enough to buy things at a price that absolutely forbids good workmanship. On the other hand, even where the pecuniary question raises no bar to considerable expenditure, it is rather a mistake for the novice to get an expensive box; he had far better get one with fewer instruments, and learn thoroughly what can be done with those, before getting what may be considered to some extent luxuries, and the preliminary failures will have been got through at the risk of damaging instruments of comparatively small cost. When the student has passed through his novitiate, has learned to take care of his things, and has, moreover, learned the real nature of the work he has to do, and what means

will most effectually do it, he can then go in for a more complete set of implements.

For a beginner, an expenditure of three or four pounds should give him all that is needful to make a very effective start: this should include a board, T square, &c.; and even half this might in many cases be found sufficient. The surest way of getting value for the money is to go at once to some good maker; his charges will probably seem somewhat high, but it must be remembered that he got his reputation by the production of good things, and that his name will be a sufficient warranty. The novice should beware of second-hand cases, as they are often considerably worn, while at other times the name veils a fraud: it is merely an attempt to pass off some worthless things that have never had a previous owner at all. It is always safer, too, to buy a set that has the maker's name stamped somewhere, either on the box or on some of the instruments.

It must be borne in mind, in calculating expense, that when the draughtsman has once got a sufficient knowledge of how to treat his instruments to justify him in getting a good set the expense comes once for all: unlike the daily bread-and-butter, an ever-recurring charge, a good box of instruments is a possession for life. The instruments we ourselves use we have had now some twenty years, and there is no reasonable

room to doubt that another twenty years may pass over them and find them less affected by the ravages of time than their owner.

It is impossible to define very exactly the box that should be procured; but no set should be considered sufficient that does not contain compasses suitable for either pen or pencil work, a ruling-pen, and a scale. In most boxes two sizes of compasses are found, one suitable for small and the other for large circles. The material of which the instruments are made is another item adding more or less to the cost; and even the nature of the case—walnut, mahogany, Russia leather, and whatever it may be — influences the total expenditure.

Where it is possible to avail oneself of the advice of an experienced friend, it is clearly a great gain to do so; or where a beginner is going to pass into some definite position, as the engineer's office of some great railway, or the training at the Royal Military College at Woolwich, he should endeavour to ascertain if any particular set of instruments receives a more especial and official sanction and approval than others, when he will do well to get it. Assuming, however, that neither of these solutions of the problem can be rendered available, that neither the aid of a friend can be invoked nor the experience of any special office utilised, our

student will do well, as we have already said, to place himself in the hands of a respectable firm, and what they will probably give him we now proceed to analyse, instrument by instrument, pointing out its method of use, how it can be most effectively employed, together with any other little details gathered during a long experience, that may be helpful to those making their first steps in a new direction.

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MATHEMATICAL INSTRUMENTS.

CHAPTER I.

Instruments used in the production of straight lines—Ruling-pen—Its construction—How filled—How selected—Advantage of having two pens—Indelibility of pen-lines—Preliminary pencilling essential—Rules for inking-in—Trials on waste paper—Importance of cleanliness—How to clean and set the ruling-pen—Common ink to be avoided—Dotting-wheels—The bordering-pen—Road-pen—Section-pen.

1. INSTRUMENTS may very conveniently, for the purposes of description, be divided into those used in the production of straight lines, those employed in making various kinds of curved lines, and those more especially employed for the measurement of lines and angles. The division here given is only a matter of convenience, an aid to systematic description, and must not be pressed home too rigidly, since clearly the compasses that appear in our second division, as the means of making curved lines, may equally well be inserted in our third section as a means of measuring lines. In the same way the protractor or the set-square, useful as a means of drawing straight lines, and therefore within the scope of our first section, may equally justly figure in our third as means of obtaining angles; while some few instruments we may probably find will scarcely fall satisfactorily within the limits

of any of the three classes. The arrangement will, nevertheless, be found in practice a sufficiently eligible one.

2. The instruments used in the production of straight lines are the ruling-pen, the T square, the straight-edge, and the various forms of set-square. To these, though it perhaps scarcely comes rigidly under the idea conveyed by the word instrument, we may very legitimately add the drawing-board, since we can by its aid, assisted only by the T square, draw any number of parallel lines and any number of others at right angles to them. In architectural drawing, for example, where so many of the lines are either horizontal or upright, the board and the T square between them do almost all the work.

3. The ruling-pen, when it is a good one, is one of the draughtsman's most cherished possessions, for the difference in comfort is something enormous between the instrument that at once responds to your wish and produces without any trouble just the line you want, and the thing that has to be drawn up and down till in the humour to mark, or that requires to be held just at one particular angle before it can be induced to mark at all. The fault is, however, more often in the owner than in the pen, since the practised hand can carefully "set" the pen, as it is termed, while the novice has the instruments supplied to him in good working condition, and it is ordinarily a want of care in cleaning that renders them less serviceable to him than they should have been.

4. The ruling-pen consists of two pieces of metal so joined together at one end that they can readily, by means of a screw, be adjusted at the free ends to any required width for ruling the lines of an ordinary drawing. The intermediate space holds the necessary ink; too much should not, however, be taken at a time, or it will probably cause a blot. On commencing work the nibs should be slightly damped; the ink

will then run easily into its place. To fill the pen with ink, it may either be dipped into a slab having slanting divisions in which the ink has already been rubbed, or it may be supplied by means of a brush; in either case the outsides of the nibs should be as little soiled with it as possible. In holding the pen for work, the nib having the circular screw-head upon it is always outwards, and it is especially necessary to see that the outer surface of the other nib is perfectly free from ink, as it is this surface that is pressed lightly against the T square in ruling, and any lack of care in this respect will almost certainly lead to a long, ragged smear.

5. In selecting a pen, care should be taken to see that the nibs are of the same length, and that they are of a sufficient thickness. In some pens the metal is so thin that the nibs really cut into the paper, and a further disadvantage is that in using the very moderate amount of pressure necessary to keep the back nib against the ruler the two surfaces of metal become nearly or quite in contact, and the line becomes uneven. It is a mistake to select too small a pen under the idea that it will necessarily enable the draughtsman to make finer lines; a pen of medium size, if in proper order, will work quite as finely, and the larger handle is far more convenient to hold.

6. In some boxes of instruments two pens are supplied. As the ruling-pen is so essential in all kinds of mathematical drawing, it is decidedly an advantage to be doubly armed, for several reasons. If, for instance, anything happens to so indispensable an implement that necessitates it being re-set, the possession of a second in reserve saves valuable time, as the work does not then come to a stand-still. In many outline drawings, too, of architectural or mechanical details it is customary to give what are termed shadow lines. These are thicker than the others, and if one pen is adjusted for the

thin lines and the other for the thick, it is a great saving of time, and far more convenient than either leaving all one series till the other is finished, or having to keep altering the adjustment. In perspective diagrams, again, it is sometimes advisable, in a complicated drawing, to represent the object in black, and the lines used in finding it in red or blue, and here the possession of two pens is again an advantage, as one can be used for each colour employed.

7. In one of the army examination papers we find a question that is almost entirely intended to test the use of the ruling-pen. The question runs as follows:—Draw a square having sides half an inch long; ink this in with fine lines, and about it place three other squares parallel to it, and one-third of an inch apart; ink these in so that each square shall have a thicker line than the one within it. Beginners will find it good practice to work this out for themselves. Care must be taken that the transition from the inner thin square to the outer thick one is gradual and progressive; there must not be too sudden an increase in any one square.

8. A very similar question to this, and from the same source, is the following:—Draw two parallel lines one and a half inches apart, divide the intervening space into ten equal parts, and draw other lines parallel to the bounding lines, inking them in with thick, thin, and dotted lines alternately. Like the preceding figure, we commend this to the novice.

9. In ruling ink lines care must be exercised in several directions. It must be borne in mind by the beginner that a line once drawn in ink is practicably indelible. Scratching out may in some cases be resorted to where the error is confined to a small and isolated portion of the work, but the eye readily detects the difference of appearance if the knife has been much in use, and it is almost impossible either to ink or colour over the place where the erasure has been made

without betraying the fact. Beginners are often tempted to hurry on to the inking; a certain amount of pencil outlining has been done, and it seems so easy then just to mark off the right points, and then rule many of the details in at once in ink. Too often, however, the fatal moment arrives; a line is taken beyond its proper termination, a detail of construction that should have gone beneath another is taken over it or through it; a measurement wrongly taken, a little piece not clearly understood, or a moment's abstraction of the thoughts from the work in hand have sufficed to work all the mischief. The student begins to realise the meaning of the old saying, that the longest way round may sometimes be the nearest way home, and he begins his drawing again full of good resolutions to get it all well pencilled-in first before he thinks of the inking. How far he maintains these good resolutions will probably decide whether the work this second time shall reach a satisfactory termination or not.

10. To those of more experience this elaborate pencilling-in of all the details is not so absolutely necessary. Where, as in the sides of the teeth of a cog-wheel, a number of similar lines all have to be drawn to one point, much time may often be saved by at once drawing these in in ink, when their starting-points and terminations are clearly defined; but even to those of riper experience misfortunes happen, and in the long-run caution pays best.

Beginners often tire of a long preliminary spell of pencil work, and want to at least ink-in what may be clearly seen to be correct. This, though it may certainly vary the monotony of the work and seem to give a greater show of progress, is not by any means advisable, and the only time when it is distinctly well to do it is when in a large and complicated drawing the pencil lines begin to rub a little. Where care, however, is exercised, and the proper amount of clean-

liness in the use of hand-paper, &c., is resorted to, there need be no fear of the blurring and obliteration of the black-lead lines.

11. In inking-in, all objects that come in front of others and hide portions of them, should be put in first, and great care must be exercised in the preliminary sketch in pencil that all back objects should be clearly marked as such. It is often exceedingly advisable to carry on a line behind an object so as to make sure of the proper continuity of the parts when it is seen again; but such lines should either be drawn much more lightly, made of a different character, or else carefully removed before the inking begins.

12. Long lines will present more difficulty often to the beginner than short ones; he feels no hesitation in drawing a line in ink two inches long, but a line two feet long is much more formidable. Assuming that the T square or ruler employed is, as it should be, perfectly true, the line may, nevertheless, when drawn by its aid, be evidently irregular; this arises from a want of care in keeping the nibs of the pen always at the same distance from the edge of the ruler. This, when stated, appears so evident a truism as to be scarcely worth formally laying down; it is nevertheless a point that in practice has to be borne in mind. A certain portion of the back nib of the pen will be in contact with the instrument employed in ruling; when this point, as in a flat ruler, cannot be very far removed from the paper level, the deviation from a straight line may not be very perceptible; but when, as in a round one, this point may be an inch or more above the surface to be ruled over, it will readily, on reflection, be seen that a very slight inclination of the top of the pen, either to or from the person using it, will exercise a considerable influence on the lower extremity also. One can, in fact, draw two parallel lines some little distance apart

without shifting the ruler at all, simply by altering the direction of the holding of the pen.

13. The pressure of the pen against the ruling surface should be equable, or the line will vary in thickness; a gradual or sudden compression of the nibs will reveal itself in the gradual or sudden diminution of the breadth of the line. Those of maturer experience can, if they choose, produce this effect when the nature of the work calls for it, but with the beginner the result is more likely to be involuntary and the effect undesirable.

14. It is often a very aggravating circumstance to note that the long line is rapidly reducing the quantity of ink held by the pen, and it becomes a matter of some little importance as to whether the supply will hold out to the end or not. It is very awkward to have to stop and replenish the pen in the middle of a line, as it is decidedly difficult to go on as though nothing untoward had happened, for the line will almost always betray the fact. The only real remedy, when such a termination is clearly impending, is to boldly stop and refill the pen some time before it gets exhausted. If the point of exhaustion has been reached, the point where the line has been resumed will always be perceptible. One soon learns by experience how far one filling of the pen will carry, and when that knowledge has once been gained, it is only want of reasonable care that leads to attacking a thing with insufficient means. We need scarcely say that the pen needs much more rapid replenishment when the lines for which it is used are bold and broad than it does for finer work. Care must be taken not to overload the pen with ink, or a big round blot as soon as the instrument touches the paper will be the penalty.

15. On commencing work the pen should always, after it has been supplied with ink, be tried first of all on a piece of

waste paper. It is not always easy to at once produce the right thickness of line, and the preliminary endeavours in this direction may well be spent on a spare fragment of paper rather than on the drawing. This piece of paper, however, should not be too unlike the sheet on which the drawing is being made, for often a pen line that will appear on trial on a piece of smooth writing-paper to be just what is wanted will, on application to the drawing-paper, produce a very different looking result. We dwell on this because we have so often found, on advising our students to try their pens first on a piece of waste paper, that their first impulse has been to dive into their pockets for a letter. Even the failures of the novice may be to some extent utilised, for when a damaged drawing is torn up, its pieces form the very things we want for trying the pens on for the next. Where the drawing is large, and an ample margin can be secured, it is often the custom to try the pens and tints of colour, &c., all round the edges, but the beginner, at least, will do well to look upon his drawing as a thing to be treated with more respect, and to be maintained scrupulously clean. A blot of ink or spot of wet colour on the margin of the drawing may get on the cuff of the coat, and will thence very readily be transferred to the centre of the drawing. A further disadvantage in using the margin of the drawing as a space to try pens, &c., on, is that very possibly some one or more of these trial lines may encroach too far. Many a time have we seen the margin of a drawing cut down far too much because somewhere a mark or two had necessitated the whole line on that side being brought in, and that in turn obliged the other side to be brought in, or the work would have been thrown out of the centre of the sheet. This difficulty may nevertheless be fairly met by at once, on the very commencement of the work, ruling a clean pencil line all round; all within this is

part of the permanent result, and all behind it may be used for trial lines and tints. This may more readily be done, and becomes more justifiable, when a drawing is "strained," as it is termed, or fastened down all round its edges to the board by means of glue and paste, for this strip all round will, in any case, be discarded when the drawing is completed and cut from the board.

16. All the tools used should be kept scrupulously clean; all rulers that go against paper should be carefully dusted; all pens should be carefully cleaned when work is over for the day; all brushes should have the colour thoroughly washed out of them. A drawing that is not covered up or put away will, in a short time, get a sufficient amount of fine dust on it to affect the working of the ruling-pen, and no work worth anything can be done if the ruling-pen itself and the inking compasses be not kept thoroughly clean. When through any oversight the ink is left to dry in a pen, it should be removed by very gently inserting the blade of a small penknife and scraping it away. If the nibs are close together, they must be opened; for the blade, if it be forced out between them at the bottom, strains the regulating screw, and this will prevent, sooner or later, its efficient action. No pen should really be left in this condition at all, for a few minutes at the end of the work may be excellently well spent in cleaning all up, and putting everything out of harm's way. Any kind of soft rag or blotting paper will do to remove the bulk of the ink from the nibs, care only being taken that the material employed will not leave any hairs or fibres behind it: after this the inner surfaces of the nibs may be very well cleaned by doubling a piece of good stiff paper into the shape of a V, and inserting it between them. The paper should not be doubled too hard; the sides of the V should retain a good deal of elasticity, as they are then

pressed against the inner sides of the pen when the paper is rubbed up and down. Many people wipe their pens on their cuffs or the inside of their coats, but order, neatness, and cleanliness are so essential to success in instrumental drawing, that the balance of success will always tend towards those who practise those virtues, and against those who ignore them.

17. The ruling-pen is, perhaps, the instrument on which success or failure most depends, seeing that it is in use almost from beginning to end of a drawing: it is, therefore, the one that will probably be the first to give out. No time should be lost in replacing it if it is hopelessly done for, or in getting it reset if it has simply got worn. Cheap instrument sets rarely contain good pens; in some they are too weak, in others the nibs are of unequal length. In this latter case a little judicious rubbing down on a stone will often put matters right. A good drawing-pen should cost about two or three shillings, the price varying a little according to the pattern, whether made of steel or electrum, and so on, while an old pen will be reset by any maker of instruments for about threepence. A little practice on the part of the owner will soon enable him to be independent of this latter aid: it is, in any case, well that he should be able to at once restore a blunted point, or rub down one that cuts into the paper. A long delay and hindrance is thus often saved; in our own case, the nearest instrument maker is, we believe, some thirty miles off. A piece of common slate and a little water will often be sufficient to do all that is needed; if oil be used, great care must be taken that all trace of it is removed before work is resumed. By using water, the success attending the setting can be from time to time tested, and any defects that show themselves on trial rectified.

18. In choosing a pen, one with good stiff nibs should

be selected, so that a moderate amount of pressure will not close them during use. A further desirable feature is seen in some pens where the lower part of the handle is made square; this gives at once a better hold, and also indicates the right direction for the points.

19. In using the drawing-pen, it should be held almost upright, and only Indian-ink should ever be employed; common ink corrodes the fine points and surfaces, and soon damages the efficiency of the instrument. There is, of course, no objection to the use of Prussian blue or crimson lake, when, as in some complex perspective or other diagrams, it is desirable, as we have seen, to distinguish various sets of lines. The only practical difficulty is in insuring a sufficient cleanliness in the pen ordinarily used for black alone to prevent its sullying the brightness of the colours. Where black and red or black and blue lines are being used in the same drawing, it is a great saving of time and temper to keep one pen specially for each.

20. In some pens the upper part of the handle is removable, and, when unscrewed, can be used as a "pricker;" the use of this we shall illustrate further on; while in others the unscrewing reveals a set of little circular discs of steel with edges variously toothed and notched. These are called dotting-wheels; they can be inserted at the bottom of the nib, the pen is then filled with ink, and the theory is that, as they revolve, they make dots or dashes, but practically the work is too coarse and rough to be of any use, and not unfrequently the first dot is a big blot, and all the others mere dents in the paper. Hand-dotting is far preferable.

21. Having now dwelt at some little length on what we may term the typical ruling-pen, we proceed to give some short explanation of some of the various modifications of form that may be met with.

22. The bordering-pen, so called from its special adaptability for making the broad borders that are sometimes put round large show architectural or engineering drawings, is something like the ordinary pen in appearance, but larger in its parts. It often has a central tongue running all down it, and almost, but not quite, equal in length to the nibs. By this means, a large body of ink can be retained for use in the pen, and a good broad line can be made without danger.

23. The road-pen is a very useful adaptation of the ordinary form. It consists of two pens placed side by side and joined together into one handle; a screw between them enables them to be adjusted to the required distance apart. Such a pen is of great service when a good many parallel lines of similar width have to be drawn; as, for example, the joists supporting a floor or roof, the lines of the roads in a topographical survey, or the metals of a railway. The price of a double pen of this character would be about six shillings.

24. The only other modification of the ruling-pen to which we need here refer is that known as the section-pen. Where a large surface has to be covered over with a series of equidistant lines, as in the representation of anything in section, for example, the lines are often so close and so numerous that it would be endless trouble to measure them and space them all out. In such case, it is ordinarily the custom to draw them by the eye, and a little practice will readily enable any one to do so, but for those who prefer a mechanical help, the section-pen will, no doubt, be an assistance, though we do not remember ever to have seen one actually in use, and have certainly never ourselves possessed one. Under these circumstances, while we refer to it as an instrument that our readers may possibly come across, we can

scarcely be expected to very warmly advise our readers to procure one. Beyond the two nibs of an ordinary pen is a third that can be adjusted by means of a screw to the required distance that the lines to be drawn will be apart. This third nib is placed on the first line drawn and run along it, while the pen portion is drawing line number two : the nib is then in like manner placed in number two while the third line is drawn, and, as the work proceeds, the lines must necessarily follow each other at equal distance, and produce an even tint. As an instrument of this kind costs five or six shillings, it will probably be regarded by many of our readers rather as a luxury than a necessity.

CHAPTER II.

The T square—Directions for its use—Must never be cut—Greek fret-pattern—Squaring-off a drawing—Materials used in making T squares—Useful size to get—Cost—Various forms of T square—Stanley square—Movable-headed square—The straight-edge—Useful size to get—Importance of seasoned wood—Materials employed for straight-edges—Straight-edge used for dividing paper—How to test accuracy of straight-edge—Needles for centres or vanishing points—The marking of points.

25. STILL confining ourselves to the means whereby we may draw straight lines, we now proceed to consider the nature and construction of the T square, an indispensable item in the equipment of the architect and draughtsman. The T square is so called from its resemblance in shape to the letter T; the long part is termed the blade, the thicker cross piece the stock. Its possession implies the acquisition of a drawing-board, as the square is of no use without it. The stock or head of the T square is pressed against one edge of the board, and all lines then drawn will be parallel to each other. The same edge should be used throughout, and the square should always, when its blade is lying on the paper, have its stock on the left-hand side of the draughtsman. Some beginners are so used to working almost everything with the right hand that they endeavour to manipulate the square in this way. In some forms of square, as in Fig. 2, where the blade increases in width towards the stock, this would be almost impossible, and in any case it is very un-

desirable, whereas by working the square into any required position by means of the left hand, the right is free to retain hold of the pencil or pen and to at once use them.

26. When the board is tilted and the paper is somewhat smooth, the T square will sometimes gradually slip down, and especially when the drawing is left for awhile, and the beginnings of mischief are not therefore perceived. It will be sufficiently obvious that a fall from the table to the floor may do the square considerable damage either in splitting the blade or loosening its attachment with the stock. To avoid this the square should either be lifted off the drawing and placed on the flat table by the side of the board, or a drawing pin may be put somewhere between the square and the bottom of the board to arrest its progress if it should begin to slip. T squares when not in use should be hung up by means of the hole that for that purpose is made near the top of the blade. They will then collect less dust and be freer from accidental risks. A T square should always in any case be wiped before using, as the dust collecting surface is a large one, and every pains should be taken not to destroy the cleanliness of the drawing.

27. If the drawing-board is well made, if its sides are true right angles to each other, a great saving of time results, as by placing the stock on the left edge all the horizontal lines can be drawn, and then by placing it on the bottom edge of the board all the necessary lines at right angles to the first series can be quickly and accurately produced. Such a method of working would be very advantageous, for example, in an architectural elevation, as all the lines of the cornices, tops and bottoms of windows and doors, lines of mouldings, string-courses, and steps, could be drawn first, and then all the lines perpendicular to these, the side walls themselves, the uprights of all doors and windows, and so on. We should use

it, again, in a plan where the various walls were at right angles to each other. In drawing the second series of lines the stock should always be placed against the lower edge of the board and not against the top. As the square, to be thoroughly useful, should always be a little longer if anything than the long side of the board, it will evidently be considerably longer than the short side. By putting the stock against the lower edge the part of the blade that projects beyond the line of the board is quite out of the way, but beginners have often a perverse way, that we could never see a motive for, of placing the stock on the top edge of the board, reaching all over their work to regulate the movements of the square, and having the long overlapping blade coming out towards them in a most embarrassing way. When the square is a long one, they can hardly get near their work at all, and any moment some movement of their body may give the end of the square a jerk that will be very detrimental to the appearance of any line that may be being drawn at the time.

28. When we come to describe the properties appertaining to a good drawing-board, we shall give a simple geometrical method by which one can readily tell if the angles are true right angles or not. The working of the T square for each set of lines is a great convenience where the lines are somewhat long, but in a good deal of drawing work the T square practically is used only for all the horizontal lines, the others, at right angles to these, being drawn by means of another instrument, the set-square, an instrument that we shall describe in due course.

29. It is always advisable, if possible, to use the same T square all through the drawing, and never on any consideration allow it to be used either by yourself or others to cut off drawings from the board. The T square may very

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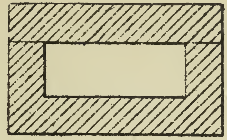

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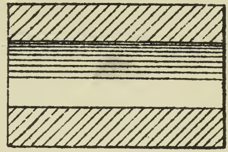

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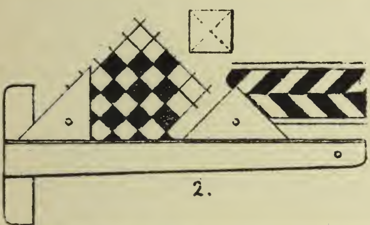

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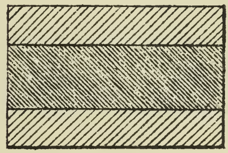

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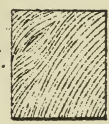

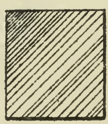

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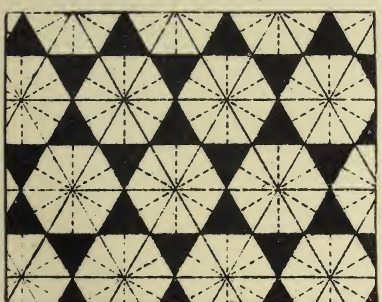

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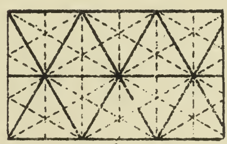

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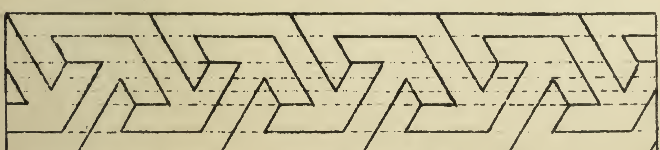

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conveniently be employed to square-off the drawing, and these pencil-lines will be the guide for the subsequent cutting-off; but it can never be too strongly impressed on the novice that one slip of the knife, making one small notch in the edge of the blade, utterly destroys the square for ruling any more straight lines. A metal or metal-edged straight-edge should always be used for all cutting work.

30. In inking-in a large drawing, or one with many lines in it, it will practically be found convenient to ink-in all the lines in one direction first, and then to turn the attention to the others at right angles to them. A great saving of time is effected, as all the time spent in shifting the square from one edge of the board to the other is economised.

31. As an exercise in the use of the T square we have given in fig. 1 an illustration of a Greek fret pattern. All the lines can be formed by the square alone. In reproducing it, divide the whole space up first into squares, as shown.

32. Where a working drawing has got so destroyed that it is desirable to make a new copy of it, this can be very expeditiously done by pinning the old drawing down on the right-hand side of the board and squaring off all the lines that run in one direction, and then fastening it down at the top of the board and squaring down all the lines at right angles to the first. This is a method often adopted in practice where no very great accuracy is called for, but it is not to be commended to the beginner, as he can only blindly copy what he sees, and he loses the inestimable advantage of being obliged to take accurate measurements step by step throughout his work. As it is, under certain limitations, one legitimate use of the T square, we here refer to it, though ordinarily it is the rough and ready way of the workshop, where time is money. and in really careful work would be inadmissible.

33. T squares are ordinarily made either of pearwood or mahogany. Of these, the pearwood are preferable, as they are not so liable to warp, and the density of the grain of the wood appears more dirt-resisting. We have always ourselves found that it was more difficult to keep a drawing clean with a mahogany square than one of pearwood. Mahogany gives an unpleasant edge, such squares, therefore, have ordinarily a line of ebony to rule against. Sometimes the entire square is made of ebony, but these cannot be recommended, as they collect dirt, and, owing to the deep colour of the wood, do not show it until mischief possibly is done. In some squares, again, a line of brass is let in along the ruling edge of the blade. Such squares can of course be used for cutting out with, but they do not ordinarily last very long. The expansion and contraction of the metal soon render its hold insecure, and, like many other things that are good in theory, it fails to stand the searching test of practical use.

34. The square employed should bear a just proportion to the work that is expected of it, and should be about equal in length to the length of the drawing-board with which it will be used. Where drawings of various sizes are made, the squares should err rather, if at all, in being over large for some of them, for the small drawings can be worked by the aid of the square that is used for the larger, but the reverse is by no means the case; the large drawings cannot be worked with a small square. The happiest arrangement in such a case, we need scarcely indicate, is to have, if possible, two or three squares of various lengths. The custom of the school or office in which the draughtsman finds himself will go far towards settling the point, as there is almost always in such cases some recognised standard of uniformity in the drawings produced, that is as nearly as possible preserved all through,

35. In speaking of the size of a square, the length of the blade exclusive of stock is always understood, so that a 36-inch T square would not go into a 36-inch box. For diagrams and large drawings T squares of 60-inches blade may be employed, while the draughtsman on wood, or the wood engraver into whose hands his work passes, use squares that are often less than a foot long. Owing to this great difference in size and in the material employed, it becomes impossible to say in an offhand way what the cost of this instrument will be to the beginner; but to quote one price alone, if the possession of a square of pearwood having a blade of some 30 inches long be deemed about the right thing, as it ordinarily would be, such a square should cost something between two and three shillings. Anything between a shilling and a sovereign may be expended.

36. Squares vary in the details of their construction, and to some of these modifications we now proceed to allude.

37. The old form of T square had the blade let into the stock, the blade itself was of one width throughout, and the stock had a rabbet that fitted to the edge of the board, and this is still the accepted form with many English makers, and remains the accepted type on the Continent. It is represented in figs. 16 and 17. What is termed the Stanley square is a great improvement in many ways on this. It derives its name from the maker, one of our most successful practical purveyors of the various instruments required for the draughtsman. We have no interest in any way in commending the wares of any one man over those of others, but, as our book is intended to be of really practical value to those seeking aid, it is false delicacy to refrain from this mention of names. The Stanley square, fig. 2, is merely a blade of pearwood or mahogany screwed on a stock; it stands, therefore, above the stock. This form of construction pre-

sents several advantages that, in practical work, are readily perceived. One of these is, that owing to the blade being above the stock, the set-square passes freely on to it, and allows of lines being ruled right to the edge of the board. Another advantage is that in case of any accident, such as notching the edge, the blade can readily be removed, and the damage set right, and then all screwed on again. In the old form of square it would be impossible to do this. The blade, too, tapers considerably, it is much wider at the stock end than the other. This form gives great strength, and prevents the deflection of the end of the blade.

38. Another kind of T square has a movable head, so that the blade can be set to any required angle with the stock, and then screwed firmly. Such a construction is valuable where a great many parallel oblique lines have to be drawn, but in practice there is not much demand for a square of this kind, as a judicious use of the ordinary T square and set-square combined will ordinarily meet every want. It must be borne in mind, too, that a movable head and screw, and so forth, all mean more work, and, consequently, more expense.

39. The straight-edge, represented in figs. 11, 12, 13, is another exceedingly useful item in the equipment of the draughtsman. It is merely a long thin strip of wood, its sides parallel, and its breadth and thickness depending on the length. The length is a very variable quantity: for small drawings, a straight-edge of some 18 or 20 inches long is very useful, but in large perspective drawings, where the vanishing points may be 10 feet or more away from the board, the straight-edge employed must be at least as long. A 24-inch straight-edge should cost about a shilling, while a 10-footer would be about half a guinea. We have ourselves repeatedly used straight-edges that could not even

be got into many rooms at all. Both edges are planed to a true straight line, and often in the larger and thicker instruments one of these edges is bevelled, so as to render it more convenient for the ruling-pen.

40. Wood and steel are the materials employed. Where wood is used, care should be taken to see that it is thoroughly seasoned, for if it is not, such long thin strips have a great tendency to warp and twist from the true line. This, however, is really a matter for the maker to see to, the purchaser can only take what is given to him, and wait till time proves either the value or the worthlessness of his purchase. It is well, therefore, to go for all things of this kind to a man who, having made a name, has a name to lose. Such purchases do not often need to be made, and economy is better studied by paying a little more for a really good thing than by buying so-called cheap things—things that will probably be a constant annoyance, hardly bad enough to throw away, hardly good enough to keep. A straight-edge now hanging in our room is, we see, dated 1867; it is as sound and true as it ever was, has been freely used ever since it was bought, and will serve us for as many years to come as we are likely to call upon it to do.

41. In some straight-edges two or three pieces of wood are glued together to counteract any disposition towards warping, and in others the centre is of one kind of wood and the two strips that form the edges are of another, the idea in this case also being to prevent twisting. A straight-edge should be of sufficient breadth and thickness in proportion to its length to give rigidity. Steel gives an admirably true line; but straight-edges of this material are about seven times as costly for any given length as wooden ones. A steel straight-edge has the great recommendation that it can also be freely used when cutting out drawings has to be done, for

we need scarcely say that a notch on the edge of a wooden straight-edge spoils it as effectually as it does a T square, and all the warnings that we have already given might well be repeated here. Steel has, however, one or two great disadvantages. It is much heavier in proportion than wood, the moisture of the hand, too, is likely to rust it, and this rust gets on the drawing, and it is, in addition, very cold to use for a great part of the year. When the temperature is low the paper and instruments are all very cold to the touch, and cold hands are a terrible hindrance to good work.

42. When it is required to divide up sheets of paper, the work can be well and expeditiously done by placing the steel straight-edge at the line of required division, holding it firmly, and then taking the paper by one corner, and, while slightly raising it, tearing it sharply down. The edge is almost as sharp as if cut by a knife. A quire or ream of paper may in this way be divided up into half or quarter sheets in far less time than by any process of folding or cutting. We place the paper squarely on a drawing-board, find out by measuring one sheet where the true division should come, make two marks on the board, one above and one below the sheets of paper at that point, place the straight-edge truly by these, and then tear away sheet after sheet without fear or failure.

43. Some straight-edges have inches or feet marked on them, but the advantage of this is, in most cases, not very great. A straight-edge is more ordinarily a means of ruling than of measuring a line. In the same way some T squares have inches marked on them, but all such dimensions can more readily be found on the scales that accompany every set of instruments. There is always a strong risk that when any one thing is set to two or three different uses, it in some degree fails in doing any of them effectively.

44. The straight-edges of any respectable maker should be

above reproach, but if the owner of one has his suspicions, a very effective way of testing the matter is to make two marks about the length of the implement apart on a sheet of paper; the straight-edge should then be placed to these, and a line very carefully drawn by its aid from one to the other. The straight-edge should now be turned over and again placed to these marks, and a second line drawn from one to the other. If one line effectually covers the other from end to end, it is a sufficient indication that the straight-edge is true. If it deviates at any given point the tenth of an inch from the true straight line, the deviation would show very conspicuously when the second line was drawn, as there would then at that point be an opening of a fifth of an inch between the two lines that should be coincident, and the eye would readily detect the error.

45. Where one's instruments are exposed to the risk of meddling, or the nuisance of careless borrowing, it is well just before using the straight-edge to run a finger along the edge; any little cut or dent will be by this means readily appreciated, or we should, perhaps, rather say ascertained, for appreciation in the ordinary sense of the word is scarcely the feeling with which we greet the damage done to our property.

46. When we have occasion to rule many lines that all go to or towards one point, it is a great saving of time and patience to put a needle into the board at this point. The edge of the straight-edge or set-square is then kept in contact with this, and one end of our required line is thus always found, and we have only to make sure of one point instead of two each time. In drawing a wheel of fifty teeth, a portion of the line of each side of each tooth would, if continued, run to the centre. If, then, having marked off on the pitch line of the wheel the starting points of these lines, we place a needle

in the centre, the hundred lines will be far more expeditiously done than if we had each time to place the straight-edge to both centre and pitch line. We find the same thing available in a perspective drawing; a needle placed at a vanishing point is in the same way a great assistance. In very large drawings, where the straight-edges may be measured by feet, a good stout bradawl firmly fixed in the table takes the place of the needle.

47. Where a point, from which a line has to be drawn is already somewhere in another line, and therefore hardly noticeable, or when from any other reason it fails to catch the eye readily, it is a good plan to take the pencil and roughly draw a little circle round it, the size possibly of a threepenny-piece. The eye then readily detects its position. Where several points require this, it will be easily seen that various methods of making them must be adopted; a small square may be placed round one, while another may have two lines at right angles, a little cross, crossing each other at the point as their centre. When some few lines have been drawn actually to the point, its position is sufficiently defined, but in many cases, as in the teeth of the wheel, though the lines would go to the point if they were continued, they never are continued, and so the position of the point therefore remains possibly somewhat hard to find.

48. Lines should always be drawn from left to right, and where a certain point marks one extremity of a line, always, if possible, let that be the starting-place. The work that starts from a dot or point is more likely to be accurate than the line that goes *to* a point. If, for example, we have a square, and we want to divide it into six equal strips by horizontal lines, we should measure off the divisions and mark off the true starting-points on the left-hand line, because, in any case, we should draw our lines from left to right, and

our work would be more likely to be accurate if we drew from a point well in sight than towards one some little distance off, and probably hidden by our right hand. Such directions may not appear of any great moment, but they are the result of some years of experience, and it is generally in the knowledge of some hundreds of little things rather than in a few great ones that the difference between the beginner and the older hand is found.

CHAPTER III.

The set-square—Its form and nature—Useful size to get—Warping, and how to remedy it—Materials employed—Framed set-squares—Cost—How to use the set-square—Section lines—The set-square of 45°—The set-square of 60°—Drawing nuts—Geometrical means of testing the correctness of the set-square—Parallels and perpendiculars—Batter lines—Earth slopes—Roof pitches—Parallel ruler—Rolling parallels—Cost.

49. USEFUL, and in fact indispensable to many kinds of drawing as the T square and straight-edge are, we proceed now to give some brief account of the set-square, an instrument of perhaps even greater value, as by the aid of two set-squares alone we can, without either of the implements we have referred to, or a drawing-board, draw any number of lines parallel to each other, at right angles to each other, or making various angles. They are therefore very useful where the work is small, as in geometrical problems, or where, owing to the drawings being in a notebook, it is impossible to avail ourselves of the aid of the T square. How these various results are effected it will be our duty to explain; but we first give some few introductory remarks as to the nature of the set-square, its forms, its material, its cost, and then we proceed to illustrate, as far as may be, the various methods of its use.

50. The set-square is a triangular piece of wood, vulcanite, or metal. One of its angles is always 90°, or a right

angle, while the other angles are ordinarily either both 45°, or one of them is 60° and the other 30°. The student will be careful to provide himself with one of each of these; they are ordinarily called "45" set-squares and "60" set-squares. They vary a good deal in size, but a "45" of six inches in length is a very useful size, and would cost in pearwood about sixpence, and in vulcanite as much again; while the "60" should be what is called a 10-inch, and will cost about eightpence, or as much again, according to the material.

51. The ordinary pear-tree set-squares are very cleanly and pleasant in use, but there is some little risk of their curling and warping by heat or damp, and where this is past remedy, the squares are spoilt, as the truth of the angles is destroyed, and the edges no longer remain straight lines. With reasonable care, however, such set-squares will prove all that the draughtsman can wish. When one of these curls with the heat, either by being too near the fire, or from being on a table with the sunshine on it, the immediate prospect is not encouraging; but if the set-square be at once turned over on the other face, it will then begin to go back, and would presently be quite as bad as before. All that is necessary is to keep an eye on it till the back curling has reached a point when the instrument is straight again, and then to at once remove it from the heat.

52. Some set-squares are built up of three narrow strips of hard wood, generally mahogany, and edged with ebony. Such set-squares are lighter than those made in one solid piece, and they have not the same tendency to warp, but the ordinary kinds are very comfortable to use, and the little additional lightness of the framed set-squares is no great advantage practically. Another advantage claimed for the framed set-squares is, that they obscure so much less of the

drawing beneath them than the solid ones do, but this again is practically no great gain, as the breadth of the framing is necessarily, for the sake of strength, sufficiently great to obscure all in the immediate neighbourhood of the line being drawn, and to see quite clearly a triangular space of the drawing some two inches or so from this is no very tangible advantage. These framed set-squares are necessarily very much more trouble to make, as the angles at which the pieces are cut must be very true, and these pieces when cut must be fastened together by metal tongues and rivets. Where large set-squares are required, and where they will be exposed to great variations of temperature, as in India, the framed pattern is undoubtedly the best. They are fully six times the price of the plain pearwood patterns.

53. Set-squares are now sometimes made of vulcanite, a preparation of india-rubber. These are very smooth to the touch, are far less likely to break by a fall or by being trodden on, can be washed if they get soiled, and as they do not warp, there is no risk of their angles or sides getting out of truth. The only objections that we ourselves feel to them, and our objections do not outweigh their good qualities, are that they are very cold to work with, and that an accidental spot of ink upon them does not show, as they are as black as ink themselves, and such a spot may very readily be transferred by the set-square to the drawing. They are about as expensive again as the solid pearwood instruments.

54. Every straight-edge, T square, and set-square (except the framed kind), has a round hole in it to hang it up by, and all these instruments are the better for this round hole being applied to its proper use. Instruments that are about on desks and tables catch much dust and are exposed to divers risks that those that are hung up escape. Boys find an ever new delight in putting their fingers or pencils through this

hole in their set-square and setting the instrument spinning, but this we need scarcely say was not the original intention.

55. By means of the "45" set-square we can readily draw lines perpendicular to each other, or lines that form half a right angle, *i.e.*, 45°. In fig. 2 we have a sufficiently clear illustration of how this may be done. When the set-square has one of its edges resting on the T square, the other two edges will either be at right angles to this and at 45° respectively, as shown in the set-square that is nearest the stock of the T square, or it may be so placed that both the edges away from the T square shall be at 45° with it. One of these lines will then slant upwards to the right and the other upwards to the left; this may easily be seen by referring to the second set-square shown in our figure. The student will have no difficulty in copying the geometrical patterns we have indicated in our illustration. It will also readily be perceived that a square may be drawn without any aid of compasses or any geometrical method. This is shown in the small figure above the patterns. A line is first drawn of the required length as a base, and then at each extremity of it lines are drawn at an angle of 45° with it; perpendiculars from each end of the base line will, where they intersect these oblique lines, give the remaining angles of the figure.

56. The set-square of 45° is also very largely used for another purpose, that of marking in an architectural or engineering drawing what parts of the objects there shown are intended to be what is technically termed "in section." This term is applied to any portion that is supposed to be cut through, and these cuttings or sections are largely used in things of complex construction, as by their means one is enabled to learn a good deal of the interior parts and those portions that are obscured by reason of others being in front of them. In an architectural drawing, for example, a section

shows a good deal that could never be gathered from the other drawings. We have in fig. 3 taken a very simple illustration. We have cut through a box, and it will be seen on a short reflection that our only way of knowing how thick the woodwork was would be by this section through it. Neither side view, end view, nor plan would give this information. In fig. 4 we have taken a longitudinal section through a piece of piping. When a section is taken in the direction of the breadth it is termed a transverse or cross section. When it is taken in the direction of the length of the object the section is called longitudinal.

57. When a section through an object reveals the fact that it is composed of different substances, this difference is shown by taking the section lines in different directions, though always at 45°. This arrangement is indicated in fig. 5. Our readers can readily realise what we mean by the simple illustration of what we should see on splitting a blacklead pencil down; we should on either side get a strip of cedar wood, while the centre would be a different substance, the blacklead or plumbago. Parts that are in section are always thus rigidly defined in line drawings, and the lines are always carefully ruled at equidistant intervals by means of the set-square of 45°. The only exception that is at all tolerated is, that sometimes in transverse sections of beams of timber it is allowable to indicate somewhat of the grain of the wood, as in fig. 6. This is useful as readily indicating a difference of material, as wood from stone or brick; but even when this is done, the general tendency of the lines should be towards an inclination of 45°, in order that we may realise that it is a piece of wood in section that we are looking at, and not merely the end of a beam.

58. Care must be taken in drawing section lines that all the lines are the same distance apart. We have already

dwelt on this in our remarks on the section pen, but the counsel, from its importance, may very well be repeated here. Fig. 7 is a type of the sort of thing done by pupils whose care fades away under a flagging interest; the begining is good, but the good start is not maintained to the end.

59. We turn now to our other set-square, the one having angles of 90° and 60° and 30°, and endeavour to point out what useful service this can render. It is at once evident that lines perpendicular to the T square or straight-edge can be as readily drawn with this as with the set-square we have just been describing, as in each case one of the angles is 90°. One great use of the "60" set-square is in its application to isometrical drawing: we may have occasion to explain the nature of this farther on, if we have space to consider what we can do with our instruments when we have got them; at present our readers must take our assertion of the great value of the set-square of 60° in isometrical drawing on trust.

60. This form of set-square is exceedingly useful again in all decorative or other work in which equilateral triangles or hexagons enter. The three angles of an equilateral or equal-sided triangle are each 60°, the triangle is therefore also equiangular or equal angled. Figs. 8, 9, and 10 are all to be worked by aid of the T square and this form of set-square: every line in all these figures is either horizontal, vertical, or at an angle of either 30° or 60°.

61. As nuts in engineering construction are ordinarily hexagonal in shape, we give in fig. 11 a ready means of drawing them by means of this set-square and a straight-edge. The set-squares are placed in position on the edge of the ruler, and it will readily be seen how they may be slipped along it and form, with the aid of the straight-edge, every line of either of the two positions given of these hexagonal nuts.

62. As the great value of these two forms of set-squares is wholly dependent upon their being what draughtsmen term "true," we give in figs. 12 and 13 simple problems in geometry by which their accuracy may be conclusively tested. Having drawn a line on the paper with the T square, assume any point in it, as A. From A as centre, with any radius, draw an arc having one of its extremities, B, in the straight line. From B, with the same radius, cut off a point, C, on the arc; and from C again with the same distance cut off point D on the arc. From points C and D as centres with the distance CD as radius describe arcs that shall cut in point E. Draw line EA, and it will be perpendicular to the original line. This line EA will cut the arc in point F. From point F as centre and the same distance as radius that we have been using all through, *i.e.*, BC, cut the arc in point G. Draw a line from A through G and it will make with line AB an angle of 30°. Draw a line from A through C and it will make with line AB an angle of 60°. By drawing this geometrical construction to a good size, say starting with a radius AB of 1½ inches, we can readily see how far our set-squares are in accordance with the true angles. The T square or straight-edge would be placed to line AB, and the set-square would then rest on it and have its three angles in turn placed at point A. If the lines of the sides of the set-square agree respectively with AG, AC, and AF, the instrument is reliable; if they do not do so, the truest economy is to discard it, as it can only be a continuous source of error.

63. To test the set-square of 45° the problem is commenced in the same way, a perpendicular line EA being drawn to AB. To get the angle of 45° we bisect the right angle BAF by drawing arcs from centres F and B; these will intersect in point G. It is immaterial what radius is employed for these arcs, care being only taken that the same radius is used

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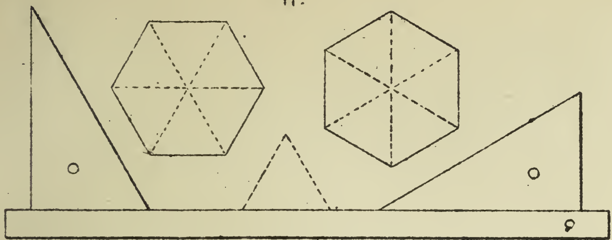

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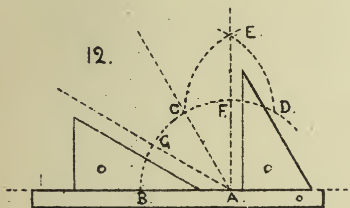

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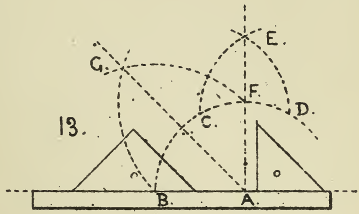

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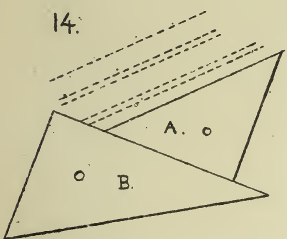

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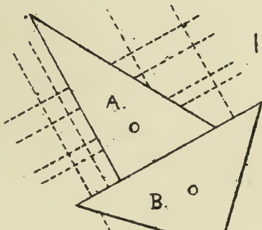

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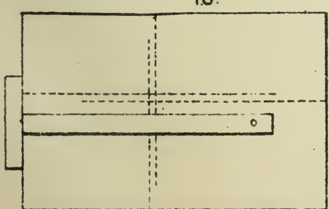

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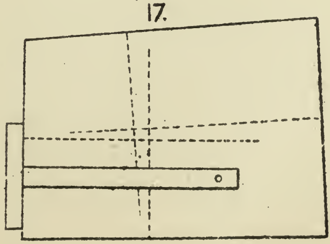


from both B and F, and that it is of sufficient size to enable the arcs to cut each other in point G. It will be evident that unless the distance taken is somewhat greater than half the distance between B and F, these curves would never intersect each other at all. The line GA makes with BA an angle of 45°. We have in each of these geometrical figures added the actual set-squares in a sufficiently approximate position to the lines of the angles to render the practical working out of the problem quite clear.

64. We have now to explain the ready method by which, by means of these two set-squares working together, we are enabled, without aid of any other ruling instrument, to draw any number of lines, either parallel or perpendicular to each other. We will suppose that, in the first place, we desire to draw a series of parallels. If our readers will turn to fig. 14, they will, we imagine, readily gather the method employed; briefly, however, it is this:—One of the set-squares in our figure marked A is placed so that one of its edges coincides with the line to which all the others are to be parallel. Set-square B is then placed in contact with one of the other edges, and firmly held by the left hand while set-square B is moved by the right hand. All lines drawn by the edge of the set-square which was used for the first line will be parallel to it. It is not absolutely necessary to have a second set-square; a straight-edge or 6-inch rule may supply the place of the second one, as all that is really needed is a line for the first set-square to travel upon.

65. To draw lines perpendicular to others, set-square B (see fig. 15) is first placed parallel to one of the first series of lines by the method just explained for drawing parallels; it is then firmly held by the left hand while set-square A is placed on it as shown. This second square is drawn along the first, and all lines drawn by its aid will be parallel to

each other and perpendicular to the first series. If our readers will only bestow a little care and give some little practice to it, they will readily fall into the *modus operandi;* and having once learned this use of the two set-squares, they will find their knowledge of constant service. A little more practice and a little more thought bestowed in addition will soon enable our beginners not only to draw lines parallel or perpendicular to each other, but also at 30°, 45°, or 60° with each other, by using the other angles of the set-squares. One great practical point to be observed is, that the second set-square must be placed gently against the first; a sudden knock or jerk at either end of it would throw it a little from its true position, and all the lines then drawn would be wrong, thanks to the false start. The thing, we readily add for the comfort of the novice, is really much easier than any written description of it is able to convey. Five minutes' observation of an "old hand" at work would at once teach the necessary manipulation.

66. For civil engineers a series of very similar things has been provided under the name of "batters and slopes." Brickwork or masonry is said to batter when the face of the work is not upright. We may see this style of construction very well in deep railway cuttings and the masonry of reservoirs, where there is a heavy pressure either of earth or water to be resisted. This battering varies, and its amount is expressed in figures. Thus a batter of 1 in 4 means that for every four feet in height the wall is one foot from the perpendicular. If, then, we cut a piece of wood into a rectangle having one side eight inches long and the other two, and then proceed to join the extremities by a straight line, this straight line will give the required angle for the face of the work, a batter of 1 in 4. Other batters are made of other useful angles, as 1 in 6, 1 in 8, or 1 in 10; and the batter, whatever

it is, is always indicated. By the use of these much time is saved, as the instrument is at once put in the horizontal line made by the T square, and the necessary slope is obtained directly.

67. Slopes are practically the same thing; they are used for sections of earthworks in railway and other engineering drawings. Where some recognised slope, such as 2 to 1 or 3 to 1, is employed, it is a decided gain to have an angle ready to hand that at once gives it. The ordinary set-square of 45° may be considered as a slope showing 1 to 1, as the sides of it that are perpendicular to each other must always be the same size, or the other angles would not be 45°. The slopes and batters are ordinarily sold in sets of half a dozen. They are only really of service to those working in the offices of civil engineers.

68. Architects occasionally use what they term pitches, set-squares cut to the various angles that are most ordinarily used in drawing the pitches or slopes of roofs. They are very similar in their nature to the batters and slopes of the engineer; we need, therefore, do no more than just briefly name them.

69. By the combined use of the T square and the "45" and "60" set-squares all parallel lines can be so readily produced that what is termed the parallel ruler is now rarely employed. It is occasionally put in boxes and sets of instruments, but it is of very little real service. It is composed of two parallel strips of wood joined together by metal bars, and playing freely on each other. When it is required to draw a line parallel to a given line, the top edge of the upper bar is placed to the line, and the bottom bar drawn down as far as the metal holdings will allow; the bottom bar is then held firmly, and the top bar is brought down to the point required for the new line. As the two metal pieces are just the same

length, the two pieces of wood will always, whether close together or far apart, be parallel to each other. The instrument has, however, many practical defects, which any one using it would soon detect, but on which we need not here linger, as the thing has grown to all intents and purposes obsolete.

70. A decided improvement on the old parallel rule is what is known as the rolling parallel. The body is composed of one long piece of vulcanite, ebony, ivory, electrum, or brass; in the middle of this a narrow opening is made that extends nearly to each end of the ruler. At each extremity of this opening a wheel is placed, and these wheels are connected together by an axle that runs from one to the other. These wheels are slightly grooved on their edges, so as to give them a better hold and "bite" to the paper, and of sufficient diameter to raise the ruler a little above the work. A strip of metal is put over the axle; it allows it perfectly free play, and at the same time gives a convenient raised part or ridge all down the centre of the ruler, by which it may be held and moved on the work as required. When the instrument is in use, one edge of it is tilted lightly down to touch the paper, and the required line is then drawn. To draw others parallel to it, the edge of the ruler is again raised from the paper, the left hand is placed in the centre of the raised bridge that protects the axle, and the ruler is gently moved on its two wheels to any required distance, its edge then being depressed again and the new line drawn.

71. A little practice will speedily enable any one to use the rolling parallel rapidly and correctly. Care must be taken that the paper is quite smooth, any little crumb or fragment of india-rubber will suffice to retard an instant one of the wheels, and then the direction of the ruler becomes slightly changed and the parallelism of lines is lost. Where, there-

fore, a great number of such lines requires to be drawn, it is well not to trust too entirely to the accuracy of each line as it follows the other, but to occasionally test the truth by running the parallel up to the first line drawn and see if it still agrees with it. When this rolling parallel is being used, the board on which the drawing is fastened should be flat, as the wheels revolve very easily, and may, if the surface be slanting, speedily deposit the ruler on the floor. The price of a rolling parallel varies so greatly—from differences in size, finish, and material—that we can scarcely say what the cost of one to our student should be. On reference to the catalogue of one of our best makers, we see that a 6-inch ebony may be got for a shilling, while a 36-inch solid brass, including a case to preserve it from harm, involves paying 100s. Somewhere within these limits the novice should, on due consideration of his pocket and the advice of those competent to give it, find the happy medium. Really good work implies both time and skill, and both these tend to make the result high in price; but in mathematical instruments nothing but really good work is good enough for the purpose. A few really satisfactory instruments are worth more than a whole boxful of inferior things, and this the daily working with either sort will very quickly prove.

CHAPTER IV.

The drawing-board—Sizes to get—Thorough seasoning of the wood—Trueness of edge—Paper to be put truly on—Rough board for cutting on—Hints on repinning paper down—Overlapping edges of paper to be avoided—Materials used for boards—Cost of boards—Cross strengthenings at back—Both sides of a board not to be in use at once—Centrolinead—Its nature and use—Various forms of it—Excentrolinead—Lengthening out lines—Drawing lines by a chalked cord—Line drawings—Various kinds of lines.

72. Though perhaps the drawing-board is scarcely an item that many of our readers would include if asked to make out a set of mathematical instruments, it is, nevertheless, like the T square, so useful, indeed so essential, an accessory, that our book would be practically very incomplete were we to fail to make some little mention of it. A drawing-board is one of the first requisites; without it, very little indeed can be done.

73. Even in so simple a matter apparently as a piece of wood to put one's drawing on, many considerations as to size, sort of material, and therefore price, come into play. As to the size of the board, it is impossible to say much, as that must altogether depend upon the nature of the work for which it will be used. In schools of art throughout the country, what is termed imperial size is the one most commonly used, because, by a regulation of the Science and Art Department, drawings sent up to London for competition for medals, &c., must be of that size. On the other hand, beginners often use smaller sizes of paper, and a large board then

becomes rather a nuisance, as it is heavy to move about, and takes up much room, either when placed against the wall or when in use on the table. The board should be slightly larger than the paper used with it; a margin of an inch or so all round will suffice; but our readers will readily see that large boards have this great advantage over small ones, that while one can do small drawings on a large board, large drawings cannot be done on a small board.

74. As a general rule, three boards, one of 31 inches by 22, another of 22 by 16, and a third of 16 by 11, would be found a most useful equipment. These sizes are known as full imperial, full half-imperial, and full quarter-imperial, as they just take either paper of imperial size, or the same paper divided in half or in quarters. The word "full" means that there is a little margin. An imperial board, as we see, is 31 inches long and 22 inches broad, while the drawing-paper of that name is 30 inches by 22. Paper, according to its size, bears many names, such as royal, imperial, colombier, double elephant or antiquarian; what these sizes are we shall more fully describe in our remarks on paper later on, but we mention them now because they give their names to the drawing-boards that are used with them. These are all called regular sizes, and will therefore always be kept in stock, though any maker will readily make any "irregular" size at a few days' notice.

75. It is most essential that the board, whatever its material, should be of thoroughly seasoned wood. Nothing is more aggravating to the temper, and destructive of good work, than a board that either splits down the middle, or so far twists that it is always in a state of rattle and unsteadiness, owing to one or more of the corners being in the air. If a board is not perfectly flat, so that it rests evenly on a table, and presents a perfectly even and uniform surface to work

on, it had better at once be discarded. As a board it is a failure, but it may make very good firewood.

76. Where the only sign of warping is shown in a splitting down the centre of the board, one is tempted to keep the board sometimes in service for awhile, but presently the fatal moment surely comes: in taking a measurement, one point of the compass is placed unknowingly right over the fissure, and a great ragged hole in the paper is the unhappy result.

77. The edges of a board should be perfectly straight, or the T square will not work truly, and they should make a right angle with each other. To test whether the board is truly rectangular or not, the T square should be applied to one of the sides, and a line drawn across the board. The square should then be shifted to the bottom, and another line drawn; these two lines should be perpendicular to each other, and to test whether they are so or not, the geometrical method given in fig. 12 should be employed. At the point A, where these lines on the board intersect each other, draw an arc, and make the construction shown in fig. 12. If the arcs that cross in point E do not have their point of intersection on the line drawn on the board, it is sufficient proof that that line is not truly perpendicular to the first one drawn.

78. We have in figs. 16 and 17 drawn two boards. The first has borne one test of the T square, the other has not. In this case, the method of using the square is indicated by the dotted lines. It is evident that if the opposite sides of the boards were parallel the lines drawn from these sides should be parallel too. This does not, however, test whether the sides are at right angles to each other; it only proves that the opposite sides are true to each other. In fig. 18 the parallelism of the lines ruled is a proof that the opposite sides are parallel, but the board is evidently not rectangular, and only the geometric method can satisfactorily test that.

79. In some boards, it will be found that the lines drawn from two of its adjacent sides are true perpendiculars, while from the other sides they are not. In this case, instead of discarding the board, it may suffice to put some conspicuous mark at that angle which is true and reliable, a star or something of that sort, and always see that that angle of the board is the bottom left-hand corner when the board is in use. The T square can then be used fearlessly on those two sides. Fig. 19 is a sufficiently clear illustration of what we mean, though to make our meaning amply obvious, we have exaggerated somewhat; for we imagine that even the veriest novice would hardly buy such a board as we have there represented.

80. Care should be exercised in putting the paper on the board. Its edges should be parallel with those of the board. This may readily be done by applying the T square to one edge of the paper, the top or left hand, and then gently pulling the paper by one or other of the corners until its edge coincides with the line of the square. If this be not done, all the lines drawn on the paper will still be true in their relation to each other, if the board and T square are to be relied on, as we may see in fig. 20, but when the drawing comes to be taken off the board it will, thanks to this carelessness at the beginning, look like fig. 21.

81. A board that is good for nothing else is often serviceable for cutting out on, for trimming the edges of drawings, for dividing up paper into halves, and so on; at all events, such work should not be allowed on any good board. The board under this treatment rapidly becomes dented and furrowed, and this departure from the perfect and ideal smoothness is soon felt when lines have to be drawn or inked-in. If nothing else can be done, one side of the board must be looked upon as sacrificed, and all cutting done on that side only.

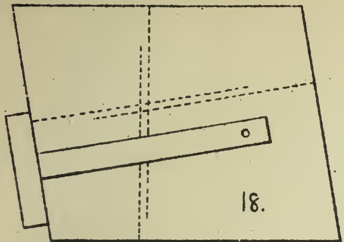
82. When drawings are elaborate, the paper is ordinarily strained by means of glue or paste. The way to do this we shall explain presently; we only now refer to it just to say that all the rough edges of paper that result from this should be carefully damped off, not scraped at with a knife. Where, as in the case of most beginners, the work is merely pinned on to the board, a certain amount of care must be exercised to shift the positions of the pieces of paper occasionally. When a drawing is once pinned down, it should not, if possible, be disturbed, as it takes some little care and trouble to see that the work is put square again; but the next piece of paper should be a little higher or lower, or more to the left or right, than the old one, or the board gets so punctured in a few places with pinholes that the pins presently lose their hold.

83. When a drawing is for any purpose unpinned and then presently replaced, the lines afterwards drawn will be untrue with those already on the paper, unless in repinning it care be taken to apply the T square to one of the lines (as long a one as practicable) already on the paper, and see that the line on the paper and the edge of the square are coincident before fastening the work down.

84. A drawing in hand, when not actually being worked on, should be covered up with a large sheet of paper to preserve it from dust, and ordinarily it will be safer to lean the board, with the drawing side inwards, against the wall, than to leave it on the table.

85. The paper should never be so large as to have an overlapping edge. When this arises, either the board must be exchanged for a larger one, or a strip must be cut from the paper. Any line of paper projecting beyond the plane of the board is a most effectual hindrance to the true working of the T square.

86. Deal as a material for boards has many great advan-



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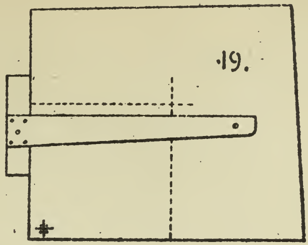

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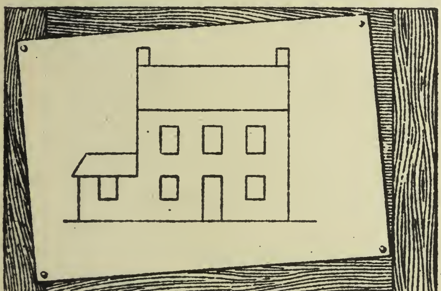

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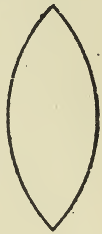

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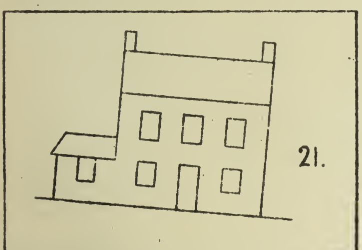

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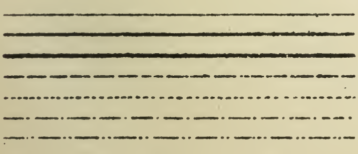

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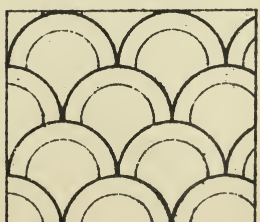

26.

tages, though there are undoubted drawbacks. The chief of these is its tendency to warp and twist, but various methods have been adopted whereby this may be more or less effectually counteracted. The advantages are—In the first place, its cheapness; secondly, its lightness; thirdly, its cleanliness; while, fourthly, we may add to these the ease with which it enables the drawing-pins to penetrate or the paste to hold. Some authorities prefer mahogany as a material, but, after an experience of both, we should ourselves distinctly prefer deal. Mahogany is rather apt to stain the back of the paper in a very unsightly way; it is most destructive to the points of drawing-pins, and in pasting paper on it its grain is so close that one not unfrequently finds that the whole sheet readily comes up again, the paste having been unable to hold. Anything like polish on the wood is very undesirable, though in some dealers' catalogues drawing-boards of mahogany are put down as either plain or French polished, the latter being at once the less useful and the most expensive.

87. Into the various technical methods of correcting warping we need scarcely go, as it is really more a question for the manufacturer than the novice. His best plan undoubtedly is to go to a really good maker, and then place himself in his hands. Any insight that we could give into clamping, panelling, mortising, or screwing-up would be of little avail without going into all the points at a greater length than is really desirable.

88. Large sizes in deal are much more liable to twist and warp than small ones. We awhile back recommended three sizes as useful for the beginner to procure. The two smaller sizes might very well be the ordinary clamped boards, and in this case their cost would be about eighteen pence and three shillings. The largest size would, if clamped, be about six shillings, but it would be very untrustworthy; and for the

extra cost of two shillings a really reliable board of the same size, but screwed at the back, might be supplied. In this latter case an engineer's board should be asked for. The prices vary somewhat according to the maker. We have bought, we see, on looking at our memoranda, boards of the same size, material, and quality at two different places; at one we paid three shillings and twopence for them, and at the other two shillings and fivepence. These were 22 by 16 inch boards.

89. It is sometimes urged against the larger sizes of boards that the necessity of their having cross-pieces screwed on to the back to prevent their warping limits their use entirely to one side. The objection is, however, more fanciful than real, as one need rarely be so sorely pressed as to require both sides of a board at once, and when only one side is wanted, it is immaterial what hindrances there may be to using the other. It is certainly far better to be at the expense of two boards, where two drawings must be carried on simultaneously, than to run the great risk of spoiling good work by using both sides of the same board. In addition to the consideration of the grave peril, it will ordinarily be found that when two drawings are advancing together, some reason exists why the draughtsman should be able to refer from one to the other, for measurements and so forth; and in this case he is far better able to consult either if they are side by side on different boards than if he has to turn the board upside down on every occasion, and never, until the drawings are finished and cut off, have a chance of really seeing the two at once.

90. Other instruments for the production of straight lines are the centrolinead and the excentrolinead. We need, however, bestow but little time on these, since, useful as they are, they will never be found in the hands of beginners. The centrolinead assumes various forms, but its use always

remains the same, this use being the power of drawing any number of radiating lines without the necessity of using the actual point from whence they spring. It will be remembered that in our remarks on straight-edges we spoke of some that were used in large perspective drawings, where the distance of the vanishing point from the actual board made it necessary to employ rulers nine or ten feet long. The centrolinead is intended to get over this difficulty. Where one has abundant room the straight-edge is very convenient, but where space is limited, and several persons have to work in one room, it is difficult to allow any one person a stretch of some fifteen feet, from point to point, of good table-room. In brief, the ordinary centrolinead is a Y-like form, a long arm or ruler jointed to two others; these smaller ones work on two studs. As the small arms are working on these the longer one always travels so that any line drawn on it would converge to the same point as any other. It is unnecessary to give the method of setting the instrument for use, but if our readers will make a Y-like form in cardboard and work it against two pins, they will gain a sufficiently clear idea of the nature of the instrument.

91. Another form of centrolinead is based on the idea that we see developed in the rolling parallel rule. In the parallel rule the two wheels are exactly the same size, while in the centrolinead one of the wheels is removable and others of varying sizes can be substituted, the effect being that all lines ruled by it become more or less sharply convergent to an imaginary point, according to the diameter of the wheel employed.

92. The excentrolinead is, as its name implies, used to draw lines that are thrown out of the general centre. If the lines of the arms of wheels, for instance, all radiated from the common centre, the arms would increase in breadth as they

approached the circumference, but in practice the construction is the reverse of this, the arms broaden as they approach the boss. The excentrolinead is useful in the drawing of a series of lines of this character, all agreeing in the measure of their excentricity.

93. In making large diagrams it is sometimes necessary to draw very long straight lines. When these are longer than any available ruler will accomplish, they are what is termed pieced-out. The method is as follows :—A line is first drawn as long as the ruler will allow, the straight-edge is then slipped along the line till it overpasses it by some two-thirds of its length, and the remaining third of the ruler is very carefully placed to the piece of line already drawn. When this has been accurately done, the new portion can then be added, and the process repeated as often as may be necessary. This way, it will readily be seen, is at best a makeshift; it is very tedious in its application, and it does not make any provision for the necessity that sometimes arises of joining two given points, the extremities of such a line. In the piecing-out process the line that starts correctly from one point may be some inches away at its ending from what should be its true termination. In this case the better method is to use a piece of cord. A bradawl or other convenient holding is put at each point; a piece of cord is then rubbed from end to end with a piece of black, red, or white chalk, and then tightly strained and tied from one point to the other. It is then taken between the forefinger and thumb at about its centre, drawn out some four or six inches, and then smartly let go; the result is a beautifully clean and straight black, red, or white line.

94. The foregoing include all the leading and most simple appliances for drawing straight lines, and we must next proceed to the consideration of the means whereby curved lines

may be delineated. We would, in closing this section of our subject, desire to say something of the lines themselves.

95. Many drawings never receive the aid of colour at all; they begin and end with being line drawings. Every line should have its meaning, and contribute to the understanding of the work. Nothing that is essential should be missed, nothing that is redundant should be tolerated. In such a case, it is evident that the beginner may give an altogether false impression; the mere putting in of a lot of lines because a space looks empty may altogether alter the character of the thing, and in the same way what are called "shadow" lines are all put in on a rigid system, and at once embellish a drawing and explain it, while an ignorant attempt at their use may lead to "confusion worse confounded," projecting shafts being shadow-lined as depressions, and round piers made to look like square ones.

96. Lines receive various names; where continuous, they are called full lines; where little spaces are left at intervals, they are called broken; while dotted lines are those where the space and the line are about equal in size. Others, again, are varied in different ways where it is necessary to follow out certain points through a drawing and to distinguish them from others; thus we may have a dash and a dot, or a dash and two dots, or two dashes and a dot following in regular sequence. Lines, too, are spoken of as fine, medium, or heavy, according to their breadth. The more distant parts of objects may ordinarily be inked-in in finer lines than the rest. Fig. 22 gives illustrations of various types of line.

97. In a geometrical problem the parts that are either given at the commencement or that form a part of the ultimate figure would be full lines, while the lines that were merely employed in the working out would be either broken or dotted. To draw an equilateral triangle on a given base, for

instance, we should start with this base as a full line, while the arcs that give us the third point of the triangle would be dotted, and the remaining two lines of the figure would, when found, be put in as full or solid lines. In a perspective drawing the actual object is put in in solid lines, and all the constructive lines in dots. Where the figure is complex, all the lines that go to the formation of one object may be in one kind of broken line, and all those used for another object in a second kind, or all lines going to vanishing points may be of a different character to all lines going to measuring points. In any drawing of machinery, again, the lines that would not be seen from the point of view given in the drawing must be of a different character to those that would be visible. We need not further multiply examples, for enough will no doubt have been said to indicate the importance of caution and the necessity of first understanding what is required and then doing it, rather than reversing this order, as the manner of some is.

CHAPTER V.

Instruments for drawing curved lines—Necessity of practice in freehand drawing—Various sizes of compasses—The bows—Spring bows—Compass joints—Fitting pencil to compass—Management of pen point—The lengthening bar—Loose joints—Compass key—Double-jointed compasses—Compass points—Large holes at centres to be avoided—Horn centres—Their cost—The use of the ink compass—Circles to be drawn before straight lines joining them—Pocket compasses—Napier compass—Pillar compass—Beam compass.

98. We pass now to a consideration of the instruments employed in the creation of curved lines. These lines are ninety-nine times out of a hundred either circles or arcs of circles. The ellipse occasionally enters into drawings of an architectural or engineering character. The arches of Westminster Bridge are, for instance, semi-ellipses, and we must presently enter into some little account of how such curves may be drawn. Other curves of a less rigid character than the ellipse or the circle may be drawn by means of instruments called French curves (figs. 30, 31), while in many cases almost all that can be done, where the curves are very irregular in character, is to pencil them in as accurately as possible, and then to go over them as steadily as the hand will allow with a fine pen, not a ruling-pen, but an ordinary fine-nibbed writing pen. One sometimes sees students trying to draw curves by hand by means of the ruling-pen, but this instrument scarcely possesses sufficient flexibility of motion to make the result successful, and in applying it to a service

to which it is not adapted, there is some considerable risk of spoiling it, and so preventing it from discharging its legitimate work.

99. Though the mathematical draughtsman can carry on his work a long way by means of his instruments, the time will presently come when these alone will not suffice. The man of ruler and compass sooner or later comes to some detail —a moulding or casting, a capital or decorative device—that can only be drawn by hand, and to him, therefore, as to other draughtsmen, the necessity of some knowledge of, and power in, freehand drawing comes home. Where a series of points has to be found geometrically through which a curve has to pass, the points themselves may be faultlessly accurate in position, but the curve drawn through them will be excellent or execrable in just the degree that the draughtsman has cultivated or neglected this practice of freehand drawing. As one piece of practical experience is worth an unlimited amount of speculative surmise and theory, we recall for the benefit of those who may be disposed to undervalue this practice of freehand drawing, and regard it as a thing outside their sphere, a drawing that we once saw in an architect's office. It represented the front elevation of some building of classic design. The lines of the pediment, mouldings, and so forth, were all carefully and neatly given, but the Corinthian capitals, the acanthus leaves feebly drawn, and all put in in lines as thick again as the rest of the work, spoilt everything. These capitals, all in a row, were perhaps a more conspicuous test and failure than one would ordinarily be exposed to; but even the smallest hand-drawn curve may prove a blemish on an otherwise good piece of work. While, therefore, in our present pages we give due importance to the various kinds of drawing instruments, it must not be forgotten that the human hand is a drawing instrument too.

100. When the novice opens his box, the greater number of the brilliant but somewhat mysterious-looking forms that greet his eyes will be instruments for the creation of curved lines. In drawing straight lines, the ruling-pen is as well adapted for those an inch long as for others fifty times the length, while the preliminary pencilling is performed by the useful "F" or "H" that does not figure in the box at all. In drawing curved lines, however, and we will at present only deal with those based on the circle, many more instruments are used. Though we may say roughly that all such lines are drawn by the compass, we find in practice the great advantage of having various sizes of compasses to produce various sizes of circles, and in most boxes three such sizes will ordinarily be found. One pair will be about six inches long when lying closed in the box; another pair, technically called "bows," will be about four inches long; while a third, the "spring bows," will be about two and a half inches long. The large compasses have one plain point, while the other may be either like it, when it is used for taking measurements, or this plain point can be removed, and either a piece in which a pencil is inserted, or one for inking-in can be substituted. The two smaller sizes do not have removable parts, but are either usable for pen or for pencil exclusively. We have, then, the large compass with two removable portions, two bow compasses, and two spring bows, all employed for the pencilling or inking-in of circles of various sizes. We proceed now to examine these a little more in detail.

101. In using the larger instrument, care must be taken that whatever portion, either the plain point, the pencil point, or the pen, is in use, should be carefully fitted into the socket. There are various forms of socket and means of accurate attachment; in some cases the principle being that of a gripping spring, while in others a screw

comes down and presses all firmly together; but whatever may be the means of attachment, care must be exercised, as we have said, to see that the junction is complete and firm. Failing this, the points will either be unsteady, when the end of a circle may decline to effect a junction with its beginning, or else, as soon as the instrument is held over the paper, the movable portion may slip out, making a dent or hole, smashing the pencil point, or producing a great smear of ink on the work in hand.

102. When the piece that is intended to hold a pencil is put into its socket, the end of it will be found to be somewhat shorter than the other leg, the plain point, of the compass. Were it the same length, the insertion of the necessary pencil would throw the thing, as a whole, longer than the other leg, an undesirable result. In fitting, therefore, a piece of pencil to it, care must be taken that this piece shall not be so long as to make much difference in the length of the plain and pencil points. A slight margin may be allowed for the wearing down of the pencil, but it must, at all events, be only a slight one.

103. Small pencils are often sold for insertion in compasses; but if these cannot be procured, an ordinary "H" pencil must be cut down. Soft-leaded pencils should never be used, as they so soon wear down and have to be re-pointed, the result being that in a very brief time they grow too short for use, and time is lost in replacing them.

104. It may seem almost unnecessary to say that a point can more readily be cut on a pencil six inches long than on one an inch long, but one so often sees beginners forget this that the caution is not altogether needless. A boy is told to cut a piece off his pencil, and to fit it into the compass, and many, if not watched, will measure the length required, cut it off, and then begin to

sharpen a point. It is difficult to do this with so very short a piece, and if the point, during the attempt, breaks once or twice, the piece at once becomes too short and has to be discarded. The point should, first of all, be sharpened, a piece of appropriate length then cut off the pencil, and then this piece as much reduced in thickness as may be necessary before it can be fitted into the space prepared for it in the compasses.

105. In using the pen point, it is unnecessary to wipe the back nib in the careful way that we do in the ruling-pen, for in the former case the pen does not come against the edge of any ruler. It is, however, important to bear in mind that no pen can work accurately or make a satisfactory line unless the two nibs are pressed equally on the paper; in drawing a large circle, therefore, the knee in the upper part of the pen piece must be sufficiently bent to enable the points to touch the paper perpendicularly.

106. When the parts are held in position by a screw, the student must be careful not to turn it so far that it comes out, or possibly the result may be a long and fruitless search for it. When the screw is once lost, the instrument is of no more use until the missing part is replaced, and this replacement means time and money loss.

107. In some boxes a plain bar, socketed at each end, is included. This is called a lengthening bar. One end of this, instead of the end of the pencil or pen piece, is fitted to the compass, and the pencil or pen piece is fixed into the other end. By this means a considerably larger circle may be drawn, though the necessity of doing so seldom arises with beginners, and those who have occasion to make such circles frequently would much prefer to use a beam compass.

108. After considerable use the joint at the head of the compass sometimes gets a little loose. In a really good working instrument the joints should be accurate and firm, and

yet capable of easy play. When a joint is too tight it is difficult to take an exact distance, as the pressure necessary to move it will often jerk the points beyond the required space. On the other hand, too great freedom of movement is at least as objectionable, as the compasses will not then stay as set, and the circle may be already drawn in ink before we perceive that the instrument has played us false. To remedy either of these faults a small piece of metal called a key is generally placed in a box of instruments. Its ordinary form is shown in fig. 23. One end, it will be noticed, ends in a chisel-like form; this is used to turn small screws; the other end has two projecting parts that fit into two corresponding openings in the head of the compass, and enable the parts to be screwed together or loosened as the case may require.

109. In cheap sets the projecting points of the compass key often do not tally with the openings they are supposed to fit, and in this case all that can be done is to borrow from some one else whose key does. We have, however, ourselves so often found that the possession of this key is a temptation to keep altering and meddling with things that are certainly not the better for such meddling, that we now quietly remove it from the boxes of all our novices. When instruments are bought at a good place, they are always supplied in good working order, and the less the screws and other parts are experimented on the better for the things, and consequently for the owner. When he arrives at "years of discretion," speaking from the mathematical-instrument point of view, he may be trusted with all that is needful.

110. In the common kinds of compasses the plain leg is made in one piece, and to this there is no objection when no circles of large size are required; but when they are, as in details of machinery, the plain leg, as well as the parts that fit into the other leg, should have a joint in it. It is impor-

tant that the piece bearing the point that is stationary in the centre should be perpendicular to the paper, as well as the pen or pencil points that are drawing the circle. Where this cannot be done, owing to the want of this knee, it will readily be understood that the compass legs, being broadly extended like a capital A, will work a large hole at the centre of the circle.

111. The centre should be only just visible during the progress of the work, and with a little care this may easily be managed. Some instruments have triangular points; these are objectionable, as the necessary rotation in making a circle soon produces a large round hole. The better sort have the ends rounded and tapering to a fine point, while others, again, have a groove into which a common needle is inserted and held in position by a screw. This is removable at pleasure, and in case of breakage a new point can readily be obtained.

112. A large hole readily forms at the centre when several circles have to be struck from it, as in drawing the lines of the teeth of wheels, the rim, the pitch line, the boss, and so on. This is more particularly the case when the wood of the board is soft deal. This hole is not only unsightly in itself, but also sadly injurious to good results, as in fine work, where there are many concentric circles, the eye readily detects a deviation, and this deviation must result unless absolutely the same point be used throughout. To obviate the nuisance, a little contrivance called a horn-centre is often used when many circles have to be struck from one point. It is merely a piece of transparent horn about as large as a sixpence, and having on its under surface three very fine steel points. These are pressed gently into the paper. As the true centre on the paper can readily be distinguished through the horn, the compass can be placed as accurately on the

horn-centre as on the paper itself. The cost of these little things should be about threepence or fourpence each; they are well worth their slight cost, and the little room they take up in the box.

113. In drawing circles in ink, the pen should be stopped as soon as the circumference is completed, or very often the line thickens when it is gone over again. Sometimes, as in shadow-lining, this is the very effect we want to produce, but where it is desired to have the line of equal thickness, no partial re-going over of any portion of it should be allowed. This is a point so readily tested that our beginners may with advantage try it, the best way of impressing the fact on their memory.

114. Bow compasses are much like those we have already been describing, except that they are smaller and that the points are not removable. Each bow is used for one special purpose, either for inking-in small circles or for pencilling them. The head is not used in rotating, as in the larger kinds, as a handle is added above it. Bow compasses are either single or double jointed. The former will make a circle of about three inches in diameter, while the latter will produce one almost double this size. It is necessary, as we have already seen, that the pen should be as nearly as possible perpendicular to the paper. In single-jointed instruments the points soon begin to lose this position, and only a small circle, therefore, can be made. On the other hand, the double-jointed bows are more trouble, as three joints have to be regulated instead of one,—the joint that works the two legs, and the smaller joint in each of the legs themselves.

115. Spring bows are the smallest form of compass made. They are ordinarily sold in sets of three, and are either placed in the general box or supplied in a small box of their own. In the latter case they should cost about seven to nine

shillings. The three instruments consist of the dividers, the ink bows, and the pencil bows. The sides are of steel and form two springs; a screw is fastened to one of the legs and passes through the other; a small nut travels on this, and by its means the two sides can be extended or compressed until the points give the radius that is wanted. The dividers are very useful in setting off small spaces and the pencil and ink spring bows will make small circles up to about an inch diameter. They are very serviceable, therefore, in drawing small nuts, bolt heads, and the like.

116. One great advantage of the spring bows is the ease and accuracy with which they may be set by means of the screw. In the larger compasses there is always a possibility that the distance at which the points are apart may be slightly altered by some little knock or jerk. In the spring bows this is not possible, and this, where a great number of similar measurements has to be made, is a very great advantage. The distance, once set, remains, and at the completion of the day's work they can be put in the box unaltered, and next morning or next year taken out again and the work accurately resumed.

117. Where a choice is possible, or, in other words, nine hundred and ninety-nine times in a thousand, it is always better to draw circles or arcs first, and then add any tangential straight lines to them, than to draw the straight lines in the first place and then unite the curves to these. This may not appear a point of any great moment, but practically it is found that it is very much easier to produce good work by the first proceeding than by the second.

118. Various modifications of the preceding types of compasses are made; with many of these we need scarcely trouble the reader, but others, such as the beam compass or the proportional, call for some little remark. Before, however,

referring to these, we may mention some few of the various forms of pocket-compass.

119. Where engineering or architectural works are actually in course of construction, the ruling spirit, be he called civil engineer, clerk of the works, or architect, will often find the great utility of simple instruments that may be carried, without damage either to themselves or their owner, in the pocket, as reference can thus, in case of any question arising, be at once made to any measurement on the drawings.

120. The most useful type of pocket compass is the Napier. When open, this forms a pair of double-jointed instruments, available either as dividers or pen and pencil points. When closed, the joints bend so far that these points are folded within the instrument, its upper part being hollowed out to receive them. It is then only about three inches long, and goes readily into the waistcoat pocket. A good pair of Napier compasses would cost about fifteen shillings.

121. The pillar compass, again, is a very useful instrument. The upper half has its sides hollow, and into these the other portions may be slipped. These other portions are the small compasses, pen and pencil, complete in themselves. When a small circle is required, one or the other is used alone; but when a larger pen or pencil circle is necessary, each of these smaller pairs is stretched open until they approach a straight line, and one leg of each is thrust into the tubular legs of the larger piece. If a pen-circle be required, the pencil compass has its pencil-end slipped into the tube and the plain end left out, while the pen compasses have their plain point thrust into the tube and the pen left out. We have now a large pair of compasses fully prepared for action. It will readily be understood that for a pencil circle of large size the operation is reversed, or both pen and pencil

points may be slipped into the tube, leaving two plain points outside for use as a pair of dividers in taking measurements.

122. The price of the pillar compasses is about the same as the Napiers. They are rather larger, as the handles of the smaller pairs do not fold in; but they are very complete and admirable instruments when well made, as they give at once the advantages of large compasses and small ones in a very compact form, and with no great expenditure of trouble, as the parts are readily shifted.

123. Beam compasses are employed when circles of large radius are required. They are, in brief, pencil or ink points which can be fitted on to a bar or tube. This bar may be of any length; it is sometimes square in section and at others round. Sometimes this bar or beam has one or more common scales marked on it; in this case the heads of the pen and pencil points have an opening in them, through which the scale may be seen. Practically, however, it is found to lead to more accurate work to set off the required distance apart of the two points of the compass, the central point and that which is to describe the curve, by adjusting them to the required distance marked off on a separate ruler. In many beam compasses, therefore, the bar is plain. In using it, the beam portion is horizontal, and the two beam heads, as they are termed, the portions that hold the points, are perpendicular to the surface of the paper. The beam heads slip readily along the bar, and as soon as the required radius is obtained, a screw at the side of each of them is brought into use, and they are securely held to the point desired.

124. The proportional compass we merely name here, as its name suggests that it has some affinity with the various instruments we have been describing, but it is in reality an

instrument for measuring distances, proportions, and areas, and will find its true place in our section descriptive of the various means of obtaining the lengths of lines, &c. Though called a compass, it has no claim to a position in our present section, the description of instruments used for drawing curves.

CHAPTER VI.

The circle in mathematical drawing—Scale form and guilloche—Ellipse —The oval—Approximations to the ellipse by means of arcs—Ellipse drawn by means of string—By means of a strip of paper—The elliptic trammel—Conchoidograph—Entasis of columns—The spiral line—Methods of drawing it—Railway curves—Splines and weights—French curves—Method of using them—Materials employed for them—Cardboard curves.

125. The various forms of compass we have in our preceding chapter described will probably, with the exception of the French curve, be the only instruments for drawing curved lines that the student will provide himself with. The necessities of engineering, geometrical, architectural, or decorative work bring the circle into especial prominence, and it is chiefly with instruments that create the circle that we, in practice, find ourselves dealing with. We have, therefore, placed all these together, and commence a new chapter in dealing with the instruments that are employed for drawing curves that are non-circular. The circle is seen in the forms of most wheels; we find it again in foiled figures, fig. 24, in the semicircular, ogee, or segmental arch, the lancet-headed window, or the vesica, fig. 25, or in the scale form, fig. 26, and the guilloche, one of the numerous forms of which is shown in fig. 27.

126. When a circle is seen at an angle it becomes an ellipse, or what, in popular parlance, is called an oval. The

two terms are not, however, different names for the same thing, and any one who professes to deal with mathematical instruments and geometrical figures should know wherein the difference consists.

127. A reference to figs. 28 and 29 will go far towards illustrating the difference of form between an oval and an ellipse. An oval, as we see in fig. 28, and as the derivation of the word would suggest, is an egg-shaped figure. One end is much rounder than the other, and though one diameter, the longer one, cuts the figure into equal parts or halves, the shorter diameter crosses it some distance from its centre. In an ellipse, on the other hand, the two diameters cross in their centres, and divide the figure into four similar portions. The long diameter of an ellipse is ordinarily called its major or transverse axis. The short diameter is termed its minor or conjugate axis. When the two diameters or axes are nearly equal in length to each other, the resulting form approaches a circle, but any proportion between the two axes is possible, from that which gives an almost circular form to one that produces a very elongated figure.

128. If the reader will take a penny or florin and hold it upright between his fore-finger and thumb, it will be represented by a circle, if a view be made of it when in one position, and by a straight line when held in another position. As the coin is slowly turned from one of these positions to the other it passes through every variation of possible elliptical form.

129. Various ways have been suggested by which approximations to the ellipse may be struck by compasses, but as the true curve of an ellipse could never form an arc of a circle these methods are all faulty at bottom. The two really practical ways of constructing the figure are either by means of a piece of string or a strip of paper, and either of these are

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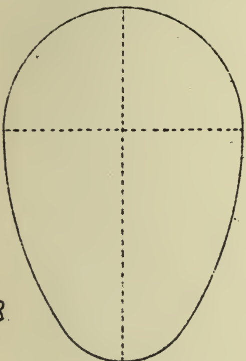

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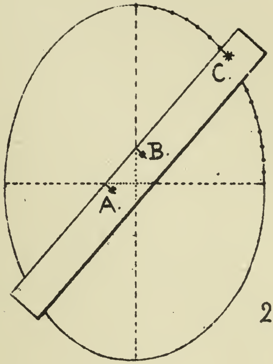

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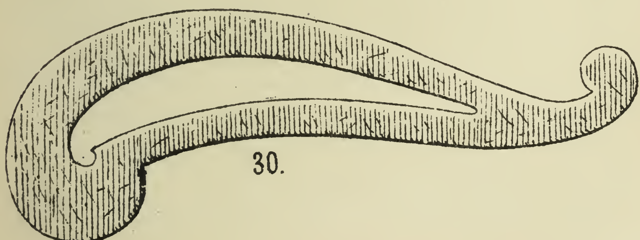

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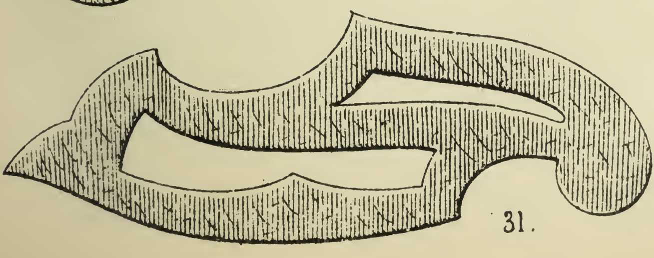

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at once so efficacious and so easy in application, that every one who deals with geometrical constructions at all should be familiar with them.

130. Where the work is large in scale the string method is preferable: the following is the method of its application. The two diameters are first placed at right angles to each other at their centres, and from either end of the short diameter, with half the major axis as radius, an arc is struck that cuts this axis in two points, the foci of the ellipse. A stout needle is now driven in at each focus, and a third is placed at one end of the short diameter. A piece of thin cord or strong thread is then fastened, just clear of the paper, to one of the focus needles, passed round the needle at the end of the short diameter, and then again secured to the second focus needle, care being taken that the string or thread is tightly stretched. The string should now look like the capital letter V, more or less flattened out according to the proportion of axis to the other. The intermediate needle, that at the bottom or point of the V, is now removed and the pencil placed there instead. The string must be kept tightly stretched, and as the pencil is drawn along in contact with it the curve of the ellipse is produced. Care must be taken to keep the pencil in one position all the time; a nearly upright one is the most effective one for work. By this method an ellipse may be readily marked out of any size; the cabinet-maker can find the true form of a table top, or the gardener can set out an elliptical flower bed fifty feet by thirty if necessary.

131. As the tension on the string tends to pull the focus needles out of the perpendicular, unsightly holes may be made in the paper at these points unless some little degree of care be exercised. For small work, say ellipses up to a foot in length, the method by means of a piece of paper is on

some accounts to be preferred, and this method we now proceed to explain.

132. The two diameters are placed, as before, in their proper relation to each other, but it is unnecessary to find the foci. Any thin strip of paper having a cleanly cut edge is now taken: this piece of paper is technically called a "trammel;" such a piece may be seen in fig. 29. Any point, as C, is first marked on it, then a distance, BC, equal in length to half the short diameter, and a distance, AC, equal to half the long diameter, is set off: points AB are called travelling points, and point C is the index point. All is now ready for use, and the trammel is placed across the diameters, as shown in our figure. Points A and B are always placed on the lines of the diameters, and wherever point C may be, a mark must be made. As many points as may be desired may be formed, care being taken to see that the travelling points are always on the two lines. When these points are found, the curve must be drawn through them by hand, it is, therefore, poor economy to shirk the trouble of finding several of these points, as the more there are the easier it will afterwards be to draw the required curve through them. We have indicated this series of points in one quarter of our ellipse in fig. 29.

133. The use of the paper trammel necessitates in the final stage hand-drawing, and this in the case of all but very practised hands is a great disadvantage. To remedy this, several contrivances, more or less effective, have been contrived, but such instruments, from their costliness, will ordinarily rarely be found amongst the paraphernalia of the beginner. On turning to the catalogue of one of our good makers, we see that one variety is priced at seven pounds, while another costs ten.

134. The elliptic trammel, based on the same principle as

that seen in the paper strip, is the simplest and cheapest, though even this means an expenditure bordering on two pounds. A piece of brass or electrum is made in the form of a cross, and a deep groove runs along the whole length of each arm. This is carefully placed on the paper, so that its central lines coincide with the diameters pencilled out. In these grooves two uprights work and support a horizontal bar: this bar has at its extremity an ink or pencil point. The uprights, it will readily be seen, correspond to our travelling points AB, while the pen or pencil point is the equivalent of point C.

135. Where large ellipses have to be made, the string method will be employed; where a few smaller ones are occasionally required, the paper edge will be used; and where the necessity of carefully drawing such figures frequently recurs, and the outlay is no bar, the metal trammel will be procured.

136. Some few other mathematical instruments for drawing various kinds of curves may be found in use, but they may ordinarily be regarded as luxuries, as the necessity for employing them will seldom arise. We need only here briefly refer to the conchoidograph and the helicograph.

137. The conchoidograph is an instrument that, as its name implies, is used to describe the curve called by mathematicians the conchoid, though it may be employed for other curves as well. The shafts of Greek columns are not straight-lined, but have a gentle curvature outwards. This curvature or entasis, as it is more correctly termed, is struck by means of the conchoidal curve, a curve so called from its resemblance to the beautiful lines of a bivalve shell. The amount of diminution varies from about one-sixth to one-fourth of the diameter. The conchoidograph will draw not only the entasis, but also all the lines of the fluting.

138. The spiral line is sometimes required in mathematical drawing, as in the spiral spring of the engineer, or the Ionic, Corinthian, or Composite volutes of the architect. Various means have been devised whereby these lines may be readily and accurately drawn, and instruments having this end in view are termed helicographs.

139. Spiral curves vary a great deal in form. In some, the lines not only continuously unwind from the centre, the point technically known as the eye of the spiral, but increase the distance they are apart as well; while in others, the lines as they unwind remain at one distance apart in the various revolutions. Any practical work on geometry will give one or more ways of striking spirals. A true spiral is continually changing its direction, and no portion of it could be legitimately drawn by means of arcs of circles; still several very useful approximations to a true spiral are produced by this method, and practically these are most useful. A true spiral has to be drawn by hand through a series of points geometrically obtained, and is, therefore, at once correct in theory and faulty in result, while in the curves struck by compass the result is only approximate, but has the greater neatness of effect that instrumental work of this character must always have on that produced by hand.

140. As we desire to make our work as really useful as possible, we have no hesitation in strongly recommending Wyndham Tarn's book on practical geometry. We have no personal knowledge whatever of this gentleman or of any one connected with him; we shall not, therefore, we trust, be uncharitably misunderstood when we advise others to get a book that we ourselves value. In this work many beautiful forms of spirals are given, together with full directions for drawing them, together with the practical applications of the parabola, hyperbola, and ellipse. The catenary curve, the cycloid,

epicycloid, hypocycloid, and others, are all explained, and the method of their delineation given.

141. Various forms of curved lines are cut out of pear-tree wood. Sets of these, varying in number from twelve to seventy-two, are largely used in the draughtsmen's offices of large shipbuilding firms, and others are used by the engineers engaged in drawing out plans for railways. As railway curves are almost always portions of a circle, our reference to these should rather have been made in the previous chapter, but they were then overlooked. The radius the curve represents is marked upon it; thus 195 on the curve means that it is struck from a centre that distance in inches away. To show the great use made of such curves, we may mention that makers advertise complete sets of one hundred and thirteen, ranging from curves of three inches to three hundred inches radius. Such a set costs between six and seven pounds.

142. Both in the ship and railway curves it may happen that some little trouble may be experienced in finding just what is required, and they, in any case, can only produce somewhat small lines. To remedy this, pieces of wood called splines are employed. These are thin strips of yew, red pine, lancewood, or vulcanite, varying in length from eighteen inches to eight feet. In using them the required curve is first sketched on the work in pencil, or a series of points in it obtained; the spline, from its flexible nature, is readily bent to the line or points, and weights are then placed at intervals on it to keep it steady and in its right position. The whole then forms a ruler along which the pen is readily guided. The cost of these splines naturally varies according to the size and material, but in any case it is not great, and any one having occasion to draw large and irregular curves would find them invaluable.

143. The weights used with the splines are somewhat more

expensive; they are of lead, the metal being covered with a casing of mahogany or other wood, both for the sake of the better appearance, and also as being more cleanly in use. The ordinary form is very like a boy's toy ship turned upside down, the sharp point of the stem coming down upon the spline. This, backed by the larger mass of metal behind, gives a sufficient hold on the wood, and the wedge-like form of the part on the ruler is the least possible hindrance to the hand when the line is being ruled. Care must of course be taken that the nose of the weight does not advance beyond the line of the ruler, or the pen will at that point meet with a check.

144. The appliances known as French curves are largely used in mathematical drawing work. They are sometimes called irregular curves, to distinguish them from those that, like the railway curves we have referred to, are portions of circles. French curves are very various in form; a reference to figs. 30 and 31 will do more to explain their nature than any written description. They are from eight inches to a foot long, and vary in price from about a shilling to eighteenpence. About fifty different patterns are obtainable, but for all practical purposes half-a-dozen will suffice. As the lines of the curves cross the grain of the wood at all sorts of angles, these implements are rather fragile; it is safer, therefore, to suspend them by a nail to the wall than to leave them lying on the work-table when not in use.

145. In using the French curve the general direction of the required lines must be first indicated carefully in pencil. One of these curves is then taken and applied to the line until a portion of the pencil line and the outline of the French curve are found to coincide, and this piece is then drawn in by the aid of the curved ruler. Another piece is then attempted and found, until by degrees all may be done.

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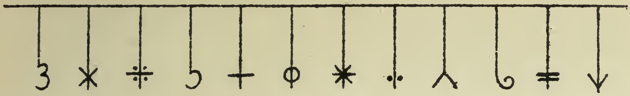

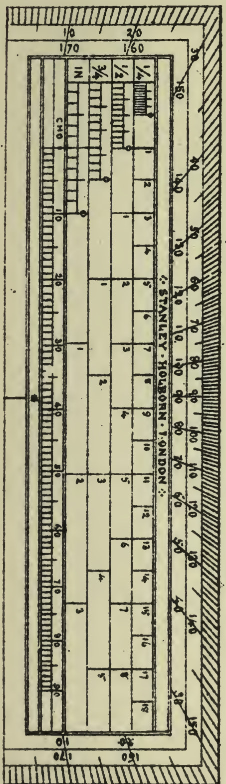

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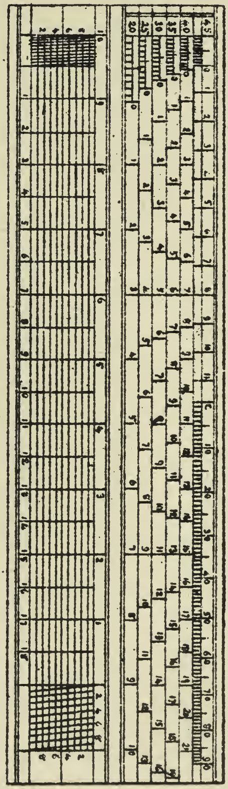

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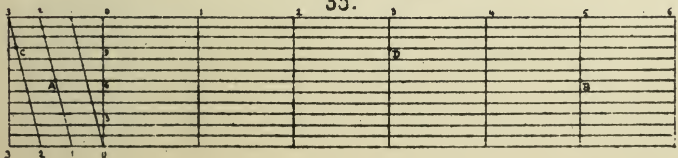


Though the continual re-piecing may appear tiresome, it is the only way to secure good work, as ordinarily only a small portion will really coincide. Great care must be exercised to maintain the continuous flow of the line; nothing like an angle or break at the joinings should be visible.

146. French curves are made either of pearwood or vulcanite. We ourselves greatly prefer the former, for though it is much more fragile, it possesses certain distinct advantages over the other. The mere difference in cost is of no great moment, for if eighteenpence will buy a more serviceable instrument than a shilling will, it is a great mistake to buy the dear one, *i.e.*, the unserviceable one.

147. One great advantage of the pearwood curve is its light colour. Where many similar curves have to be drawn, as, for example, the lines of the thread of a screw, it is a great advantage to be able, when the curve is once formed, to mark it off on the edge of the instrument. By this means absolute identity all through the work is obtained. Owing to the black colour of the vulcanite composition this valuable aid to work is lost, as any pencil or ink marks on its edge would be too indistinct to be really serviceable. Various little marks may be used, the beginning and end of each portion of any particular curve being distinguished by the same mark. A dozen of these are represented in fig. 32, and our readers, when they see the sort of thing required, will have no difficulty in devising some few dozens more. A French curve that has seen good service will often be marked all along its edges by these marks, the records of past work.

148. Where a thing is alike in curvature on either side of a central line, the French curve is first correctly placed and marked for one side, and then turned over and the marks carried to the other side. By this means, when the drawing is inked-in, the two sides will be identical in character.

149. As we have seen that a curved line of any length may require the application of half-a-dozen different portions of the French curve to produce it, it is sometimes an advantage, when such a line occurs several times in a drawing, to cut one's self entirely away from the tedious aid of this instrument. This may be done without imprudence by first drawing the required curve very carefully on a piece of good cardboard, and then with equal care cutting it out. Cardboard, after a little while, owing to the friction and pressure of the ruling pen, becomes soft and untrue on its edge, but this disadvantage will hardly appear before the temporary curve has effected its purpose. If it gives indication of wear, all that is necessary is to place it on another piece of card and mark off and cut out a new line before the old one is destroyed.

CHAPTER VII.

Dividers—Directions for their use—Stepping out a measurement—Great accuracy essential—Geometrical methods for dividing a line into any number of equal parts—The division of a circle—Geometrical figures based on polygons—Accumulation of error in setting out divisions—Centre lines—Triangular compasses—How employed—Methods of drawing an irregular figure—The pricker—Copying drawings by its aid.

150. We proceed now to consider some of the commoner means employed for finding points, measuring lines, or constructing any required angles. The first two sections run naturally into each other, for though, as we shall see, we do not always, in finding points, at the same time ascertain measurements, the one ordinarily follows on the other.

151. The instruments known as dividers are the simplest and most familiar method of finding any required points. These instruments are found in almost every box, though in some cases the compasses take their place. They resemble the compass, except that in these both legs end with a sharp point; where these are not supplied, the compass has not only a pen and a pencil leg, but also a plain leg, that can take their place, thus forming a pair of dividers. Where a good deal of work is done, it is a great saving of time to have a pair of dividers as well as compasses, and in any case the less the legs of the compasses are shifted and altered the better. We ourselves always keep one compass ready with the pen-joint and another with the pencil-point in, so as to be able to

pass at once from one to the other as the work demands; and any one who has much compass work to do will soon fall into the same plan.

152. Dividers are chiefly useful when several similar measurements have to be made. The points should be very sharp, and the joint at the head of the instrument should have that ready facility of movement that may be termed the happy medium between a too great looseness of the parts and an over-stiffness in the working. Where the parts are too loosely fastened, there is great risk that a slight movement, at the time imperceptible possibly, may throw out the measurements, while it is difficult to get the measurements at all when the parts are too tightly screwed up. The instruments decline to move without the exercise of considerable force, and when this force is applied they will suddenly open to a point that is, at all events, not the point required, and the patience of the operator undergoes a certain amount of strain.

153. In using the instruments, great care must be exercised not to make unsightly holes and dents in the paper; the touch must be as delicate as will at all suffice to mark the point. A row of minute holes along a line may be almost unnoticeable at first, but when the line is inked in, they will assume a very undesirable prominence. The dividers should be held without stiffness, and, like all kinds of compasses, only by the head, as any pressure on the sides of the instrument will almost certainly affect the measurement.

154. The required distance should be very carefully obtained in the first place, as the slightest error multiplies itself when this dimension is "stepped out," as it is technically termed, along a line. The distance that on the first measurement is a hair's-breadth out, is two hair's-breadths wrong on the second stepping out. A very slight inaccuracy when set off twenty times along a line will throw matters out an inch

or so by the time the end of the line is reached. This is often a source of great annoyance and perplexity to beginners in setting out polygons in a circle; all appears to be going well, and then when the last side is set off, it is either too long or too short, and all has to be gone through again. The student should never, in stepping out such distances, mark the paper in any way until the successful arrival at the end of the line justifies it; if the last division is wrong, all are wrong, and any marks made will only become sources of error.

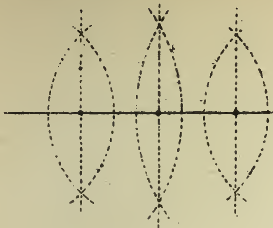
155. Where a right line or circle has to be divided out into any number of equal parts, a little consideration beforehand will often greatly simplify the work. When a straight line has to be divided into an even number of parts, such as 2, 4, 6, 8, 10, the most accurate method is to bisect and re-bisect as far as possible. Continuous re-bisection will give us 4 or 8 parts without further labour; but in the case of 6 or 10 we can only divide the line once by this method, and must then in each half place either 3 or 5 equal parts. Even then the gain is considerable, as we only have to step half the distance to ascertain the right size; for if one half is rightly found, the other follows as a matter of course, whereas if one measurement is wrong we find it out when half the line is reached, instead of having to go from end to end before the error is detected. A line divided into four equal parts by re-bisection is shown in fig. 36.

156. Where a straight line has to be divided into any uneven number of parts, as 7 or 13, the geometric method given in fig. 37 is preferable. A line, AB, is drawn from one extremity of the line to be divided. This line may make any angle with the first, and may be of any length. On this line, AB, with any distance, seven equal parts must be set off with the dividers, and a line is drawn from the last of these to the other extremity of the line to be divided, and lines

parallel to this are drawn from all the other divisions on line AB.

157. It is of course a matter of indifference whether the parts set off on AB reach to the end of the line or not; all that is necessary is that the last part, wherever it falls, should be joined with the extremity of the line to be divided. In our figure the seventh point just falls on the end of the line, but this is a mere chance. It will be at once evident that if the problem required the whole line AB to be exactly divided by spaces that just took up its length, one might as well, and in fact far better, divide the other line at once. This method can be employed for any number of sides. We only dwell on it here because it is especially useful for an uneven number.

158. In dividing out a circle, 3, 4, 6, 8, 12, 16, and some higher numbers based on these, are very readily obtainable. Two diameters drawn at right angles to each other will at once give four equal parts; the bisection of these will give eight and the re-bisection sixteen. The beginner will soon find, too, that the radius of a circle will just go six times round its circumference. Mathematically the ratio of one to the other is not exactly one-sixth, but the difference is so slight that for all practical purposes it is non-existent. If, then, a diameter be drawn, and the radius marked off on the circumference from each extremity, as in fig. 38, the circle is divided into six equal parts. If this distance is only marked off from one extremity of the diameter, the circle is, as in fig. 39, divided into three equal parts, while by drawing two diameters at right angles to each other, and from each extremity of both then marking off the radius, we get twelve equal parts, as shown in fig. 40. If all the points are joined successively in fig. 38, a regular hexagon will be inscribed in the circle; in fig. 39 the result will be an equilateral triangle, and in fig. 40 the figure will be a regular dodecagon.



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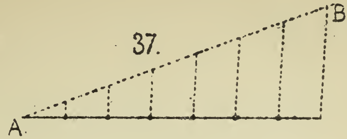

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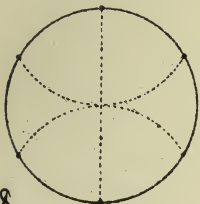

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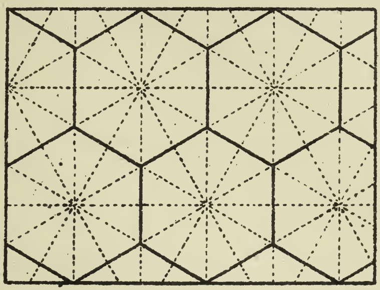

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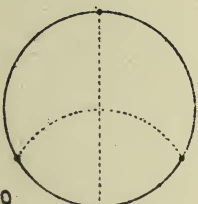

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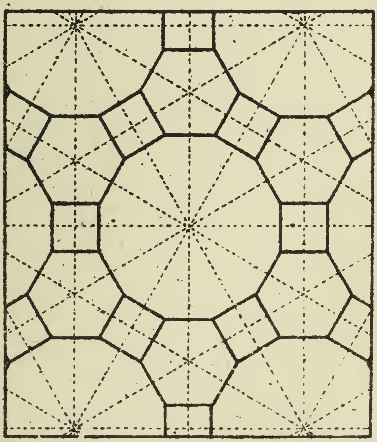

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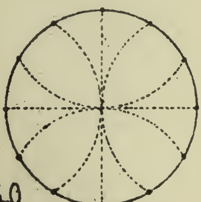

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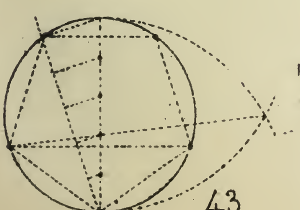

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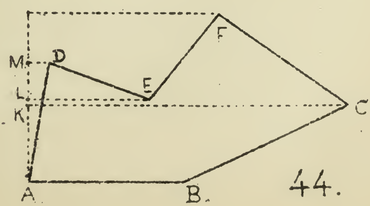


44.

159. Figs. 41 and 42 may be redrawn to a larger scale by the student, as a piece of useful practice in finding regular hexagons and dodecagons. The latter figure, it will be seen, is made up of dodecagons, hexagons, and tetragons or squares. Each of these figures will be a useful exercise in neatness and accuracy of drawing, for, failing these, the designs will never come out true to copy.

160. The use of the radius is a great assistance in setting out any multiple of six; thus, for example, if we have a wheel of forty-two teeth, we should first divide the pitch line of the wheel into six equal parts and then divide one of these sixths into seven. This would take some little time to do, but when once done the required measurement could then readily be carried all round by filling in the remaining five-sixths with the same distance that was found to be right for the first sixth.

161. In the same way that we found in fig. 37 a ready geometric means of dividing a line into an uneven number of parts, we can by the aid of another geometrical construction divide the circumference of any given circle into any number of equal parts. As the use of diameters and radius will not meet every case, for instance, 5 or 7, we give a method that is more especially adapted to these conditions. We may mention that there are special methods for finding almost any number of equal parts on the circumference of a circle, one way being specially and exclusively for 5, another in the same way limited in its application to 7. 8, 9, 10, and so on, have all their special methods, and these may readily be found in any standard work on geometry; but for practical purposes, if the student knows thoroughly one general method by which any number of divisions may be obtained, he has knowledge sufficient for all ordinary needs. The necessity for a good sound knowledge of at least the

elements of geometry is so essential for all who would have any dealings with ruler and compass, that it seems almost superfluous to dwell on it. Those who have not this knowledge may very readily acquire it in its most useful form by the study of Rawle's "Practical Plane Geometry," a manual almost absurdly cheap in price. It is most judiciously written, for it gives every needful problem, while its pages are not cumbered with the many fancy problems that some writers indulge in and that have no practical value. We have ourselves long used it and commended it to our pupils, and we are glad to have this opportunity of still further doing so.

162. The general method for dividing a circle into any required number of equal parts is as follows:—The circle being struck, a diameter must be drawn. This diameter is divided by the problem shown in fig. 37 into as many equal parts as divisions are required on the circumference. Arcs are then drawn from each extremity of the diameter, and having the length of the diameter as radius. From the point where these arcs intersect each other a line is drawn through the second division on the diameter and continued until it cuts the circumference; the distance from this point to the nearer end of the diameter is one of the required distances. If this distance be taken and set carefully round the circumference, it will mark off the required number of spaces. This is the method employed for drawing polygons of any required number of sides, these points on the circumference being the resting-places of their angles. It must be noted carefully, that whatever the number of sides wanted, the line must always be drawn through the second division on the diameter. We have given this exceedingly useful problem in fig. 43.

163. Where the parts are small, as in setting out sixty divisions for the teeth of a wheel of eight inches diameter,

the spring-bow dividers are almost indispensable. We have already in our remarks on spring-bow pen and pencil compasses explained the way in which the finest divisions and measurements may be found and preserved by means of a screw action, and this advantage is equally great in the case of the dividers.

164. Where the circumference of a circle has to be divided into any number of equal parts, it is always well to draw a diameter lightly as a preliminary and start off the divisions from one extremity of this. The advantage of this proceeding is similar to that which we have already seen in bisecting a straight line. The diameter divides the circle into two equal portions, and we thus discover, with half the labour in stepping out, whether our distances are correct. Where the required points form an even number, as 6 or 10, the half-way point should coincide with the end of the diameter, and if it does not, we at once see the necessity of beginning anew with a fresh measurement. Where the sides form an uneven number, as 5, 7, or 9, the method is not strictly so applicable, but in practice it is nevertheless found to be an advantage, as the eye readily detects, when the half-way distance is found, whether the diameter point bisects it or not.

165. After a distance has apparently been carefully taken, it may be found that the last point either slightly exceeds or falls short of the true position. In this case the dividers should not be hastily and thoughtlessly shifted for a new attempt, but it should be borne in mind that this error has been a gradually accumulating one, and has arisen from a slight inaccuracy that has increased with each measurement, If, then, in setting seven equal divisions round a circle or from end to end of its diameter, we find at last that the seventh point overlaps a quarter of an inch, we must gently close the dividers to what we judge to be one-seventh of this distance.

If our judgment has been correct the second attempt will be successful. If, on the other hand, our last point falls short, we must extend the point of the dividers to what we take to be one-seventh of the distance we have lost.

166. A little practice will readily enable any one at the first or second attempt to get the required divisions properly spaced out. We must, however, impress on all beginners the necessity of absolute exactness. "That's near enough" has spoilt many a drawing, and has been as fatal to good work as that other familiar refuge of the lazy, "We can put it right in the inking-in." A circle that should have thirty-six equal divisions, but has really only thirty-five equal parts and another of about two-thirds the proper size, may not, on a cursory glance, be noticeably wrong, but on the completion of the work the unlucky tooth or cog that is only two-thirds as big as any of the others becomes wofully conspicuous.

167. In measuring off work from a piece of machinery or some architectural construction, or when copying another drawing, centre lines should as much as possible be found and worked from. Most details of engineering or architectural works have some considerable degree of symmetry in their arrangements; centre lines of shafts can be marked, axes of columns found, and the like, and the work thus methodically arranged and set out in the drawing has far less chance of error creeping in than where this basis is not employed.

It is often an advantage to be able to determine readily the relation of three points to each other. By the use of the common dividers we ascertain the position of a second point in relation to the first, and by the use of what are termed triangular compasses we find the true relation of one point to two others. This instrument is especially useful in land sur-

veys, as the plots are frequently very irregular in form. We have in fig. 44 a representation of one of these plots.

169. In making a copy of this irregular figure we might employ either the dividers, the common compass, or the triangular compass, and the method of use in each of these cases we will now proceed to give. It is understood that the figure is in each case to be the size of the original.

170. The readiest way of drawing the plot ABCDEF by the aid of the dividers would be to fix, in the first place, on any one of the lines, as AB, as a base, and to draw a line AV perpendicular to it. Lines parallel to AB should then be drawn from all the other points until they touch line AV; these lines will cut in points KLMV. The distances VF, MD, LE, and KC can then readily be obtained, and the true position of the angles of the field determined.

171. To draw this figure by means of the ordinary compass we take any one line, as AB again, as a base to work from, and having drawn such a line on our paper, we measure the distance from A to D, and draw a line having that radius from centre H. We then measure the distance from B to point D again, and with this radius, and point B as centre, we draw another arc cutting the first; the point of intersection will give us point D on our drawing. From either lines AB or AD we may, in the same way, determine point E by finding intersecting arcs, and either lines AB, AD, or DE will give us a base line from which we find point F.

172. The point to be found should lie well between the two points of the base from which the arcs are struck, or it becomes difficult to tell the exact point at which the arcs really intersect. In copying our figure our readers would soon detect this, for they would perceive that while the intersection of the arcs at point C was very clear when they were struck from points E and F, it would be very difficult to

determine the true point, owing to the great similarity of direction, if the arcs to find angle C had been struck from points D and E. The same disadvantage would be felt in a minor degree if we took points A and B to find C by; A and D would be much better.

173. The principle of finding the position of a third point when we know the position of two others, can, it will be seen, readily be determined by this method of intersection of arcs, but the triangular compass arrives at the result much more quickly. To find point D by the intersection of arcs, we (1) draw a line, AB, and (2) measure its correct length: we then (3) from A determine distance AD with compass, and (4) draw this arc on our paper; we next (5) find distance BD, and also (6) draw this on our paper. By using the triangular compasses we arrive at the same end as follows: We draw (1) an indefinite line on our paper, we then (2) place the compasses so that the three points rest on AB and D in the example we are copying; and we, in conclusion (3) place two of these compass points on our indefinite line, their resting-places giving us at once the positions of A and B, and the third point at the same time marking the position of point D. We in the same way triangulate the rest of the figure. One of the collateral advantages of the use of the triangular compass is, that the point is at once obtained, a slight dent or a pencil point being made to mark it, while in the other case a good deal of pencil work has to be rubbed out when the arcs have been used.

174. In our remarks on the use of the protractor we shall indicate a method by which, by the aid of that instrument, any irregular spaces, like that shown in fig. 44, can be either enlarged or reduced.

175. Where drawings of a bold and simple character have to be copied, the use of the pricker is at times an advantage.

All that is really required is a fine needle, but as this by itself is somewhat difficult to hold and to exert pressure on, this needle-point is either fitted to a special handle of its own, or the top part of the handle of the ruling pen unscrews and is used for it. Where much pricking through has to be done, it is as well to have this instrument complete in itself, and not part of any other. A pricker can be bought for a shilling, or a very good home-made one can be made by means of a needle, a penholder, and sufficient strong thread to bind one securely to the other.

176. Several copies can be made at once by placing the requisite number of sheets of paper beneath the example, and pricking the points at once through all of them. This is a very speedy way of reproducing simple working drawings, or making copies of irregular forms without need of either intersecting arcs or triangular compasses.

177. The practical points to be observed in the use of the pricker may be readily summed up. In the first place, the process should hardly be applied to an original drawing that is so far valued that a number of little holes all over it are an objection. In pricking through, great care must be taken that the original and the paper beneath do not shift on each other: it will be very difficult to get them right again, and, if they are not got right, all the work afterwards done is wrong in relation to what has gone before. The two papers should either be pinned down, or a weight placed on some part not being worked at. Where the drawing is at all complicated and the transferred points numerous, one corner of the original should be from time to time sufficiently raised to allow some number or arbitrary device to be placed on some of the leading points. There is a certain danger of the papers shifting in doing this, if a considerable degree of care be not taken; but, if it be not done, the student will find, after he has been

laboriously pricking away for some time, that, when he at last removes the original and looks at his paper, it presents to his dismayed eyes some dozens of holes scattered over the sheets: suggestions of which it is hopeless to make use, as it is impossible to see, amidst them all, what points have to be joined. This is no fancy sketch or imagined possibility: we have ourselves seen this look of dismay, and "what has been may be."

CHAPTER VIII.

Scales, their nature and construction—The representative fraction—Reading to edge—Duodecimal scales in common use—Diagonal scales, their construction and use—Decimals—Other scales found on protractors, &c.

178. Various scales will always form a part of the equipment of the draughtsman. Drawings made to scale, as it is termed, are representations of some object, and bear some fixed relationship of size to it, so that, when we once know what this scale is, we are able to find out the real size of the object that is represented. To this end the scale of the drawing is either named on it or actually drawn, the latter being far preferable. Ordinarily drawings are made of less dimensions than the constructions or forms they represent, but in some cases, as in drawings of microscopic preparations, the reverse is the case.

179. If a drawing be made to a scale of six inches to the foot, it is at once seen that its parts are all half the size of the corresponding parts in the real thing: such a drawing would be said to be half scale. In the same way, if a plan be drawn to the scale of an inch to the mile, we see that a distance that really measures four inches and a half represents a distance of four miles and a half.

180. Sometimes the scale is represented on a drawing by what is termed its representative fraction. This indicates what proportion the drawing and the original bear to each

other; thus a drawing half the size of the object would be marked as $\frac{1}{2}$, *i.e.*, one foot in the drawing is the representative of two feet in the real thing. A drawing of a yard to the mile would have $\frac{1}{1760}$ as its representative fraction, because what is represented by one yard is, in the real thing, a distance of one mile, or seventeen hundred and sixty yards.

181. The scales that are more commonly used in land surveying, mechanical, or architectural work are drawn upon rules of boxwood or ivory, and placed in the instrument box. By means of these much time is saved, as the draughtsman does not need to draw the scale, nor take his dimensions by compass from it, but can at once, when the divisions read to the edge of the rule, place his scale to the drawing, and tick off the required distance at once on any line by means of the pencil. In the same way, when it is desired to know what the real size of any detail in a drawing may be, the edge of the scale is at once applied to it, and its dimensions read off. The scales we most often find on these rules are the $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, $\frac{3}{16}$, $\frac{3}{8}$, $\frac{3}{4}$, $1\frac{1}{2}$, $\frac{5}{8}$, $\frac{7}{8}$, $1\frac{3}{4}$, $1\frac{1}{4}$, $2\frac{1}{2}$, and 3 inch. These are, in each case, divided duodecimally; *i.e.*, the last division to the left is divided into twelve equal parts for inches. A drawing, therefore, of $\frac{7}{8}$ths of an inch to the foot would have a real distance of 2 feet 5 inches represented by a line that was as long as two spaces of $\frac{7}{8}$ths of an inch each plus five of the twelve parts into which one of the $\frac{7}{8}$-inch spaces was divided.

182. To set out a scale, we must know what relation in size the original thing and the drawing are to bear to each other. We will assume that, for some reason, none of the scales named above are applicable, and that it becomes necessary to draw one for ourselves, and we decide that our drawing shall be in the proportion of three and a half inches to the foot. To make this scale, we commence by drawing a line

and marking off on it a series of spaces, each three inches and a half long. Each of these spaces we reckon as one foot. We now take the left-hand division and divide it, by the method shown in fig. 37, into twelve equal parts for inches. We then call the inner end of this last space 0, and from this zero we number off our feet consecutively to the right and our inches to the left, so that the numbers from the left-hand end of the scale would run as follows:—12, 0, 1, 2, 3, &c. If now we want to take a measurement of 3 feet 7 inches, we place one end of the compasses at figure 3, and extend the other leg until the point has travelled seven-twelfths of the distance beyond zero; or if the scale reads to the edge, we at once tick off a distance that corresponds with these points in the scale.

183. As some of our readers may scarcely comprehend what we mean by "reading to the edge," we give in fig. 45 an example of a scale that does so read. A very slight inspection of it will show that all the divisions are carried to the edge of the rule, and that any distance by it could at once be marked off. In contrast to this, our readers will see in figs. 33 and 34 examples of scales which do not read to the edge. The chief use of this instrument is to find angles by, as we shall see presently, and these scales are merely placed in the parts that would otherwise be left blank, an arrangement that is at least far more serviceable than bare wood or ivory would be. The scales in fig. 33 are the inch, the three-quarters, the half, and the quarter-inch, and it will readily be seen that to transfer any of these to the drawing, it would be necessary either to mark them off carefully on a straight-edged strip of paper, or take them off with dividers. The scales could not, as in fig. 45, be directly applied to the drawing. The scales on fig. 34 are decimally divided, the divisions being 45, 40, 35, 30, 25, and 20 to the inch respec-

tively. If we want to find a distance of 65 feet on a plan drawn to 20 feet to the inch, we place one leg of the compass on figure 6 and the other on the fifth division to the left of zero, because each of the divisions to the right of zero represents spaces of ten feet, while the space to the left of zero is similar to these, but has the single feet marked on it.

184. The line of chords as the part marked "Cho" in fig. 33, or "C" in fig. 34, is called, is generally put on the scales supplied, but it is very rarely used, as whatever it can do for the draughtsman the protractor will do better and more readily. Like the latter, it is used for finding angles: its method of use will be found farther on, when we consider the application of the protractor, sector, and other angle-measuring instruments.

185. The lower part of fig. 34 is taken up by what is called a diagonal scale. As the principle of the thing is very good, we will describe the method of drawing one. A convenient unit of measurement is taken and marked off on a line, and numbered from zero to the right, and one space of equal length marked off to the left of zero, as in making a plain scale. In a plain scale we get two dimensions, as feet and inches, but in a diagonal scale we get three, as yards, feet, and inches, miles, furlongs, and chains, or units, tenths, and hundredths. The scale represented on fig. 34 is of the latter description; there are, in fact, two on the rule, that to the left being a quarter-inch, and that to the right a half-inch scale: the figures of the former read along the bottom line, and of the latter along the top line. This is the actual representation of the ordinary form of ruler supplied in instrument boxes; but in fig. 35 we have an enlarged rendering of a diagonal scale adapted for yards, feet, and inches, and in fig. 46 another for reading units, tenths, and hundredths, the larger size being clearer for the purpose of explanation. In

setting out a diagonal scale, the units to the right of zero are the largest denomination, and those to the left of zero are the next largest, while the third denomination is set off down a line at a right angle to this.

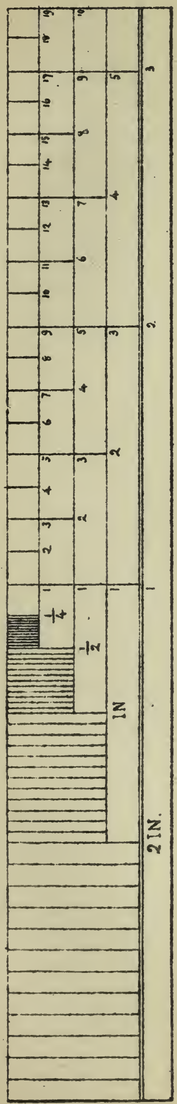
186. If the student will refer to fig. 35 he will see six divisions set off to the right; these are yards. The left-hand division is divided into three parts, because there are three feet in a yard. A line of any convenient length is then drawn at a right angle to the first, and on this twelve equal divisions are marked, because there are twelve inches in every foot. Had the divisions been representative of miles, furlongs, and chains, the unit to the left of zero would have been divided into eight, because there are eight furlongs in a mile, and the line perpendicular to it into ten, because there are ten chains in a furlong. Lines parallel to the first are now drawn, as shown in fig. 35, from all the divisions that mark inches, and lines perpendicular to these from all the divisions that mark yards. The divisions that indicate the feet are marked on the top and the bottom line in the left-hand space, and joined by lines that are each one division out of the perpendicular, 1 being joined to 0, 2 to 1, and 3 to 2. It is this portion of the construction that has earned it the name of the diagonal scale, though the oblique-lined scale would have been a preferable name, as these slanting lines are not diagonals at all.

187. Having now made our scale, we must learn how to use it. As all the horizontal lines are the same distance apart, the spaces between 0, 0, and the first oblique line 0, 1, will diminish in a regular proportion, and if the space 0, 1, on the top line represents one foot or twelve inches, the space cut off on the next line will be a twelfth less, or eleven inches, and so on, each diminishing space being one inch less. The spaces cut off on the horizontal lines by the slanting lines

1, 0, and 2, 1, and 3, 2, are all equal to each other, and in every case represent feet. If, then, we want to take a distance of 5 yards 1 foot 6 inches from the scale, we place one leg of the compass at A and the other at B. This will give us a length of five yards and one foot and six-twelfths, or inches, of another foot. All the yard and foot spaces are equal on whichever line we measure them; we therefore only need to count up whatever the number of inches may be, so that in this case we measure on the sixth line from the bottom. To give one other example, we will suppose that we require a distance of 3 yards 2 feet 9 inches. In this case we should count nine lines up the yard line marked 3, and extend the compasses to C, thus getting at one operation three complete spaces of yards, two of feet, and nine-twelfths of the remaining foot, a distance indicated in our figure by CD.

188. If we have succeeded in explaining with sufficient clearness the principle of construction and method of use of the scale, fig. 35, of yards, feet, and inches, the student will have little difficulty in comprehending the diagonal scale we have represented in fig. 46, by means of which tenths and hundredths may be found. In almost all geometrical examination questions, as, for instance, those for candidates for commissions in the Engineers, Artillery, or the Line, the dimensions are given in decimals. If the candidate has to construct some figure on a line 3.83 inches long, and cannot draw the line, all the superstructure that he would have reared upon it falls to the ground.

189. On the protractor, fig. 34, the diagonal scales bear the proportion of 200 and 400 parts to the inch respectively, as in one case 100 parts are represented by half an inch, and in the other case the 100 parts are represented by a quarter of an inch. In our illustration these distances are greatly



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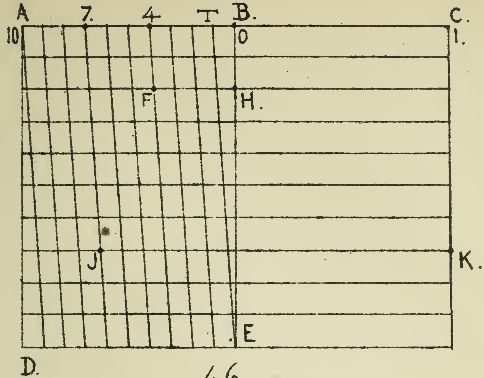

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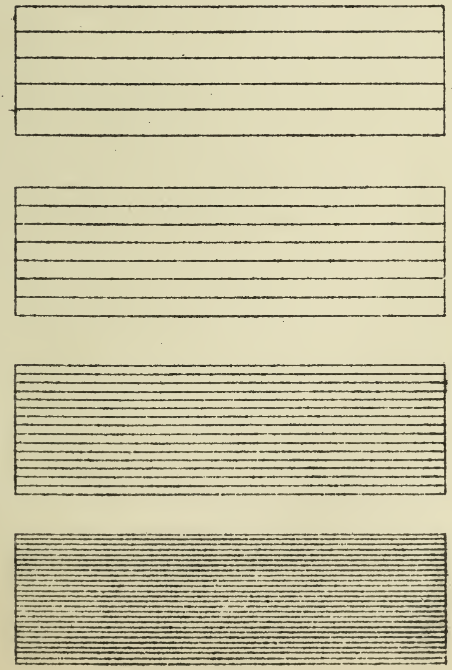


47.

reduced, but it will be readily seen that the finely divided portion at one end is as large again as that at the other, and if our readers will examine the six-inch protractor in their instrument case, they will find that these distances are really quarter and half-inch spaces.

190. Though distances in the questions in examinations are ordinarily given in inches, tenths, and hundredths of inches, and could be at once taken off by means of a scale of 100 parts to the inch, these reduced scales of 200 and 400 to the inch are very readily employed. If we have a scale of 100 to the inch, and want any given distance, as 2.13 inches, we take it at once from it; but if we have only the 200 to the inch scale, we take the distance 2.13 on that and double it; or if we use the 400 to the inch scale, we take the measurement by that and then set it off four times.

191. The scales of 200, and especially of 400, to the inch have the further advantage that by their aid we are readily enabled to set off lengths of greater magnitude than any given on the scale. If, for example, we want to find a line that shall really be 18.43 inches long, we find the representative of that distance on the 400 scale, and then step it along the line four times to obtain the result. Such measurements should be very carefully taken, as any error either of shortcoming or excess repeats itself fourfold.

192. To construct a diagonal scale that shall be available for measuring inches, tenths, and hundredths, we first draw a line and mark off on it a series of spaces as ABC, making them each one inch long, if we propose to have a scale of 100 divisions to the inch, or half an inch long if the scale is to 200 divisions to the inch, or a quarter of an inch long if 400 divisions to the inch are required. The left-hand division, AB, we now divide into ten equal parts, and we draw another line, AD, at right angles to this. Line AD may

be of any length we choose, but whatever length we make it, we must afterwards divide it into ten equal parts. Practically, therefore, the better plan is to draw the line indefinitely, and then commence setting off from A ten equal parts, afterwards rubbing out any part of the line that may be over. From all these divisions we draw lines parallel to ABC. The points on AB are now to be transferred on to DE, and the two sets of points joined by oblique lines in the way shown. For beginners, it is always well to have the points set off both on the top and bottom lines, but it is really only absolutely necessary to have them on the top line, as the experienced hand will place the set-square true with TE, and having drawn that, will slip it along in the way we have already explained in dwelling on the uses of the set-square, and draw all the other required lines parallel to the first from the succeeding points on the top line.

193. If our explanations have been followed up to this point, our readers will have little difficulty in the application of the principle of the diagonal scale to practice. Press of space has compelled us to only show one distance, *i.e.*, from B to C, to the right of zero, but in practice we should mark off some four or five spaces each equal to 0, 1. We will now assume that we require to find the measurements .7 inch, 1.4 inch, .38 inch, and 1.63 inch on our scale. As the distance from A to B represents an inch and is divided into ten parts, if we count seven of these from B, we obtain the first measurement required; it is B 7 in our figure. The next distance, 1.4 inch, is shown by the distance C 4 in our illustration. The next requirement, .38, is the thirty-eighth of an inch divided into one hundred parts. It is shown by FH, three complete divisions, equal to three tenths or thirty hundredths, being taken, and eight tenths of another part being added to them. As the number we have required ends with eight, we count up

to the eighth line from E, and then measure along it. Had we wished .37 instead, we should have stopped one below point H, and reckoned on that line instead the three complete tenths and the seventh of the remaining tenth. The last measurement, 1.63, is shown by JK. To obtain it we count up three lines from E, set one leg of the compasses at K for the one inch and the other at J, six complete tenths for the .60 and the small space, equal three tenths of one of these spaces, for the remainder.

194. A little practice should render the use of the diagonal scale very easy, complex as it may appear when a description merely is read. Our readers should not rest content, however, with any mere verbal account, but endeavour to make scales of this character for themselves, taking any three consecutive values, as miles, furlongs, and chains, perches, yards, and feet, and the like, and then setting themselves various measurements to find out. Let five furlongs, for example, be represented by an inch, and then find a line 2 miles 2 furlongs 3 chains long; or a perch being represented by three inches, let a line 3 perches 2 yards 1 foot be obtained.

195. Besides the line of chords, many other mathematical lines may be found marked on the scales supplied, but most of these will be very rarely, if ever, used by the ordinary draughtsman. The lines of sines, tangents, and secants are used for the various projections of the lines of the sphere, the meridians, parallels of latitude, &c. The line of rhumbs is employed to lay down or track a ship's course on the chart and to calculate the run made, and the line of longitudes is in the same way employed in the science of navigation, and a description of its application would be foreign to our present aim.

CHAPTER IX.

The Marquois scale, its construction and examples of its use—Cost—Natural and artificial scale—Section lines—Proportional compasses—Scales of line—Enlargement or reduction of drawings—Scale of circles—Division of circles into equal parts—Scale of plans—The determination of areas—Scale of solids—Determination of bulks—Cost of proportionals—Wholes and halves—Eidograph—Pantagraph—Measurement of angles—The protractor—Division of the circle into degrees, minutes, and seconds—Similar and equal figures—Line of chords.

196. We have yet to consider the Marquois scale, the proportional compass, and other means of dividing and measuring lines, and to the first of these we now turn our attention.

197. The Marquois scale, so called from the name of its inventor, is rarely used except for military drawing. As, however, the name figures in every mathematical instrument catalogue, and there is really no reason why the things should not have a more extended use, we give some little space to a consideration of them.

198. A set of Marquois scales consists of two flat rulers and a triangle, and these, from their bulk, are ordinarily supplied in a box by themselves, the price for such a set being about eight shillings. Each rule is a foot long and has four scales on each face, sixteen scales in all, of which eight—the inner eight—are called natural scales, while the others—those on the outer edges—are termed artificial scales.

The natural scales give respectively 20, 35, 30, 35, 40, 45, 50, and 60 divisions to the inch, and the artificial scales that pair off with these on each edge have in every case their divisions three times as large as those of the natural scale with which they are associated. Each artificial scale has a zero point in the middle of it, and the numbers run right and left from this. The set-square that accompanies these scales is a right-angled triangle, its hypothenuse being exactly three times as long as the shortest side; it bears, therefore, the same proportion to it as the artificial scales do to the natural. A short line headed by a star or fleur-de-lys is drawn about the middle of the hypothenuse, and the longer of the two remaining sides is bevelled down for convenience of drawing lines either in pencil or ink. All the instruments are made of thick boxwood, and will stand a good deal of usage. The principle involved in their construction is based on the second proposition of the sixth book of Euclid.

199. The Marquois scales and angle together will often greatly facilitate work, producing various constructions with much neatness, accuracy, and rapidity. They are to some degree at once the equivalents of set-square, straight-edge, parallel ruler, and dividers, and the student will readily discover many ways of rendering them useful. If, for example, we desire to draw two parallel lines at a distance of $\frac{13}{35}$ apart, we draw the first line in the required position and place the edge of middle length of the set-square in contact with it throughout its length; we now place the ruler having the scale of 35 parts to the inch on it against the hypothenuse of the triangle, so that its zero point coincides with the index line on the set-square, and we then slide the set-square along the edge of the scale until the index point coincides with the thirteenth division from zero. The line we are

then enabled to draw will be parallel to the first and at the required distance from it. As the divisions in the artificial scale are three times their nominal size, the measurements are more readily and accurately taken, and any slight error is proportionately reduced, so that what appears to be a hair's-breadth out is really only a third of that distance wrong. To draw a line perpendicular to another, we place the shortest edge of the set-square to the first line, and then place the ruler against the longest side. We then slide the set-square along the ruler until its third edge cuts the line, and any line then drawn will be perpendicular to the first. For practice, the student may draw two lines $\frac{17}{60}$ apart at right angles to two others $\frac{12}{45}$ apart.

200. We have in fig. 47 taken four spaces; the first of these we have divided into five equal parts, the second into seven, the third into fifteen, and the last into twenty-five, the work all through being done by the Marquois scales alone. For the first of these we employ the "40" scale; we draw the first line with the bevelled edge of the set-square, then place the scale against the hypothenuse, so that the zero on the scale and the index point on the triangle coincide, or "read into each other," as it is technically termed. We then slip the set-square along the edge of the ruler, and as the index reads into every eighth point along the artificial scale from zero, we draw a line, because there are eight fives in forty. If we had wanted twenty, we should have taken every other one; if eight, every fifth; if ten, every fourth. In the second example we have used the "35" scale, and drawn a line at every fifth point. To get the third series, the fifteen lines in the given space, we have taken the "45," and then drawn a line at every third point on the scale. It is evident that we might also have obtained it by using every other line of the "30," or every fourth line of the "60" scale. In the

last example, twenty-five divisions in the given space, we have used the "50" scale, and taken every other division on its edge. Our readers, when they have once grasped the principle and method of working, will find no difficulty in multiplying examples indefinitely.

201. One of the great difficulties of the novice, as we have already seen in our remarks on the common set-square of 45°, is the even drawing of a series of section or other lines. Though the student of riper experience finds little difficulty in drawing them by the unaided eye, the beginner often gets them very irregularly spaced out. It will be obvious on reflection that the Marquois scale, or any other evenly divided ruler that has its divisions coming up to the edge, could be employed as a guide, the set-square being slipped along it and stopped at each division. All the lines so drawn must necessarily be equidistant.

202. Proportional compasses. This useful and ingenious instrument is composed of two flat and similar pieces of metal, each having a point at both ends, and held together by a sliding piece that travels freely up and down the central and hollowed-out portion of them, or by means of a screw can be held firmly in any position when required. Proportional compasses are used to enlarge or reduce one drawing from another, so that all the lines of the example, or the solids and areas expressed by them, shall all bear in the reproduction any desired proportion or ratio. They can also be used for dividing circles into any number of equal parts up to twenty, a problem that often arises when polygons have to be drawn, or the positions of the arms or teeth of wheels marked, and square and cube roots can be determined.

203. Our readers, on taking the instrument in their hands, will notice that on its four plain surfaces, the long strips that on each side of the instrument bound the open central portion,

various scales are engraved. These are figured and named, those on one face of the compass being marked as lines and circles, while the other two, visible on turning the instrument over, are the scales for plans and solids. To prepare the instrument for use, or "set" it, as it is technically termed, all that is necessary is to close it accurately, so that each pair of legs covers each other, and then move the slider until the line engraved across it reads into the required division upon any of the scales. Having got this, all that remains is to tighten the screw, and the instrument is ready for use.

204. The most ordinary use of the proportional compass is the reduction or enlargement of drawings, an operation that it performs with beautiful accuracy and celerity, and entirely doing away with the tedious process of taking every measurement off first from the original, and then from the enlarged or reduced scale. The *modus operandi* is as follows:—The scale marked lines is taken, and the line of the slider moved until it agrees with the required number, as, for example, 4; the instrument is then tightened up, and any measurement taken will be as 1 is to 4. If, then, we use one pair of points, as, for instance, the longer legs of the compass, and apply them to any measurement in the example, the other pair of points will always mark one-fourth of this. On the other hand, if we take the measurements with the other end of the compass, the second pair of points will always show distances equal to four times those taken. The ratio between the measurements will always be as 4 to 1, and we can, as we choose, use either end of the instrument to take the first measurements with, and the alternative end will, at our option, give us either a distance a fourth of this or four times as great.

205. To divide the circumference of a circle into any number of equal parts not exceeding twenty, we turn to the scale of circles and set the slider to the required number.

We then open the longer legs to the length of the radius of the given circle, the distance apart that this opens the shorter legs being the required length. If, for example, we let the slider read into the figure 8 on the scale, and set the longer legs to the radius of the circle that we wish to divide, the opening made by the shorter legs of the compass will go just eight times round this circle.

206. It may at first sight appear a disadvantage that the scale of circles should only be available up to twenty divisions, but practically this drawback need not be much felt. If, for instance, we want to divide the circumference of a circle into twenty-one equal parts, it would, at all events, be a clear gain of time to divide it first accurately by means of the proportional compass into seven equal parts, and then by trial to divide one of these sevenths into three equal parts. The distance once found would readily be applied to all the other sevenths. To obtain twenty-two parts, we should first find eleven and then bisect each part, or we might still more expeditiously arrive at our result by drawing two radii at right angles to each other, and taking the point where each touched the circumference as the starting-points of two series of elevens. To obtain thirty divisions, we might either obtain fifteen and then bisect them, or else find the distance that would be correct for a pentagon, and set this off round the circle six times, starting successively from one of the six points that we could first so readily, by means of the radius, divide the circumference into. We need not multiply examples, for we are sure that a little reflection on the part of the beginner will readily indicate what course to pursue in most cases.

207. The scale of plans is exceedingly useful where it is required to draw areas in any given ratio. Various geometrical methods are available for this purpose, but the propor-

tional compass produces the result at once. To effect this we bring the slide down until the line on it reads into the required line on the scale. If we, for example, set it at figure 5, a square or triangle having a side, or a circle having a radius, represented by the width we open the larger pair of legs will be five times the area of a similar figure pricked off by the shorter pair of legs. We can at our pleasure use either pair of points for our first measurement, and then the second pair will either give us an area of one fifth the first figure or of five times its area.

208. The remaining scale, that of solids, is employed when we wish to produce drawings that shall give any given ratio between the capacities of two bulks or solids of similar character. As the way of setting the instrument is the same throughout, we need not detail it, but, as an illustration of its use, we may suppose that we have made a drawing to measurement of a timber stack, and that we wish to find out how large another of five times the cubical contents would be, or how much smaller a pile of one-fifth its bulk would appear. Having adjusted our slider to figure 5, the alternative pair of points to those applied to the measurements in the drawing would at once give the necessary increase or decrease.

209. Our readers who propose to provide themselves with an instrument so useful can scarcely complain of the cost being somewhat high. On referring to a maker's catalogue, we find that the cheapest six-inch proportional compass costs a little over a sovereign, and a nine-inch instrument more than as much again. While the busy man of large practice and scanty leisure will at once avail himself of so valuable an instrument, for its services to him will soon repay its cost, the novice, whose needs are not so pressing, nor purse possibly so well lined, will do well to defer the purchase awhile. Every-

thing that the proportionals can do can be done by other means, and it will do the beginner no harm to have to learn the different geometrical methods and principles by which various problems have to be met by those who do not possess this instrument.

210. Wholes and halves, or bisecting compasses, as they are sometimes called, are sometimes useful, but they are costly in proportion to their use, and the student would do better to procure a pair of proportionals instead. Wholes and halves are like a big and a little pair of compass points joined together by a head common to them both. This head is one-third of the distance from one pair of points to the other, so that whatever distance we open the little pair, the other pair are opened as much again, and whatever distance, conversely, we open the larger pair, the small pair open to half as much.

211. Where it is required to make plans either half or twice the size of an original drawing, these compasses would at once be available, but practically so many other proportions are required for which wholes and halves are of no service, that we can only reiterate our advice, and urge the beginner to get proportionals instead. A very slight increase of cost will give an instrument that will do all that the wholes and halves will, plus a great deal more. The chief value of wholes and halves is, as their second name implies, for making bisections. This they undoubtedly do very quickly and accurately, but whether in most cases it is worth while to spend a sovereign in an instrument to do this opens up another question entirely.

212. The eidograph and pantograph are other ingenious contrivances for enlarging or reducing drawings, but both lie beyond the sphere of the beginner's operations. Should he, however, desire to possess either or both of these, the

prices in each case range from about twelve to sixteen pounds.

213. Two or three instruments for obtaining angles now remain to be mentioned. The one in most ordinary use is the protractor. We have in fig. 33 a representation of the commonest form, while another is shown in fig. 48.

214. Circles, irrespective of their size, are in all kinds of mathematical work considered to be divisible into 360 equal parts; each of these parts, or degrees, as they are technically termed, is divided again into 60. This secondary division is in turn divided in like manner; so that, put into table-book form, the facts would run as follows:—60 seconds one minute, 60 minutes one degree, and 360 degrees in a circle. In mathematical drawing we rarely, however, get beyond degrees and half-degrees, and the division into seconds is for this purpose purely theoretical.

215. As it would be very tiresome to be always obliged to write the word "degrees" after the figures marking them, a sign has been adopted instead. A small circle is placed after the number, and level with the top of it, so that 72 degrees, for example, would be always written 72°.

216. Both the rectangular protractor, fig. 33, and the semicircular protractor, fig. 48, are figured for 180°, and this is ordinarily all that is required. Where more than this is wanted, a circular protractor is required; on this, of course, all the 360° are marked. If our readers will notice our two illustrations, they will see that the bottom edge is quite plain except that in its centre it has one line. This line is ordinarily marked by a star or some such device, to render it more conspicuous. Around all the other edges of the rectangle or the arc of the second form of protractor a series of radiating lines will be perceived. These lines, if continued, would all meet at the outer end of the star-marked line.

Every tenth line is numbered, and the fifth or half-way line between each of these figured lines is made a little longer—a sufficient guide to the eye.

217. When any angle has to be set off from a given point, the protractor is placed so that its lower edge coincides with the first line of the required angle, and having the central point on this line accurately placed at the spot where the angle has to be made. The eye then runs along the line of figures until the desired angle is found, when a pencil-tick is made at this point, and a line joining it with the desired starting-point of the angle is drawn. This second line makes with the first the required slant or angle.

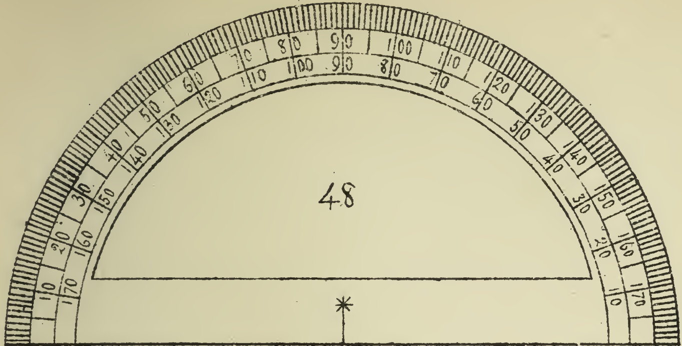
218. Beginners are often puzzled because the same line on the protractor bears two very different numbers; thus one is marked as 30° and 150°, or 10° and 170°, or again 80° and 100°. A glance at fig. 49 will, however, explain this. For it will be seen that while at point A we draw the required angle, BAC, of 30°, we at the same time create another angle, DAB, and this angle is 150°. The total of the two angles will always make 180°. A very little practice will, however, enable a beginner to see which is the line he really wants.

219. The three angles of any triangle when added together should make 180°. In the set-squares we see that one of them has one angle of 90° and the other two of 45°, while the other common form has them of 30°, 60°, and 90°. In each case the total is 180°. We can, therefore, construct an equilateral triangle by means of the protractor. For if it is equal-sided, it must also be equal-angled, and these angles must then each of them be one third of 180°, *i.e.*, 60°. The beginner will find it good practice to draw some irregular triangles, and then measure their angles by means of the protractor: as he knows what the total should be, he can readily add his results together, and see how far his readings

are correct. The product of 90, 40, and 50 would show a correct reading; the product of 80, 90, and 12 an error. If, then, we know by measurement what any two angles of a triangle are, it is superfluous to measure the third.

220. We will suppose that we desire to know what angle two lines would meet at if continued, the actual continuation being for some reason impracticable. The problem is presented to us in fig. 50. EF and HI are two lines that converge, but the point of convergence falls beyond the paper. All that is necessary is to draw a third line, JK, across them anywhere in their length; find what the sum of the two inner angles would be, and the difference between that and 180° would give the angle at which lines EF and HI would meet. In referring to any angle, its apex is denoted by the central letter; thus in fig. 50 we say angle KJF, because J is the point at which the lines KJ and FJ meet; it would be altogether misleading to call it JKF, JFK, KFJ, or FKJ. Bearing this in mind, we are now able to refer to the angles in our figure. On testing these with the protractor, we find that IKJ is 113° and KJF $35\frac{1}{2}$°; the lines EF, HI, must then be inclined to each other at an angle of $31\frac{1}{2}$°

221. Rectangular protractors are generally made six inches long, and either of wood or ivory, while the semicircular or circular ones are made ordinarily of brass, though electrum is sometimes employed. The price of an ordinary six-inch boxwood protractor should be about eighteenpence, and of a brass one about twice as much. Horn and paper are sometimes employed. A six-inch semicircular horn protractor would cost about a shilling. Their transparency is sometimes an advantage, as they do not obscure the drawing they are placed over, and one risk or error in joining wrong points is thus avoided, but they are rather given to cockling up. The brass semicirculars, as may be seen in our figure, have a large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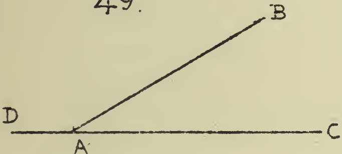
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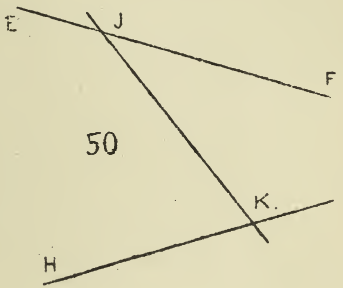
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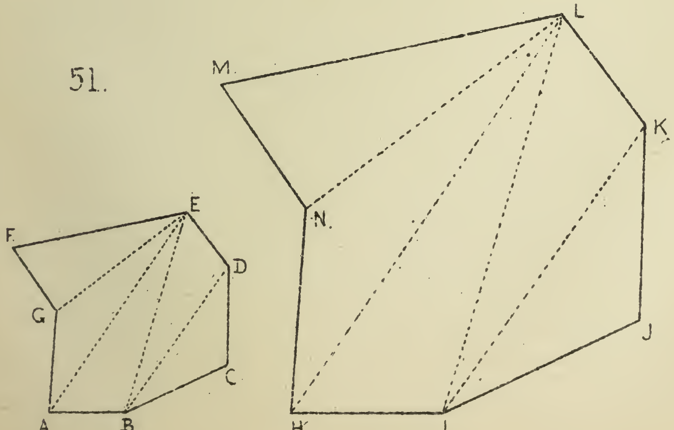
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opening in the centre, and this is practically as safe as the transparency of the horn.

222. Paper protractors are somewhat different in character. They are printed on square cardboard, and give an entire circle. Instead of marking off the degrees from the outer edge, as in the other kinds, they are marked off from the inner, the whole of the interior being cut away. The general look of the thing, therefore, is that of a card about a foot square, and having a large round hole in the middle of it; all round the edge of this opening the degrees are marked. As the central point from which all the lines radiate is cut away, another method of reading off the degrees has to be employed. Two lines are drawn at right angles to each other, by means of the T square and set-square, through the point at which the angle has to be drawn, and these lines are made long enough to reach the divided edge of the protractor. The instrument is then shifted about until one line coincides with the 0° and the 180°, and the other into the two 90°. The only advantage that this form possesses is that a series of lines at various angles can be drawn from this central point without having to move the protractor away each time a line is drawn.

223. Any triangle, we have seen, will have the sum of its angles 180°: if our readers care to increase their practice in the measurement of angles, they may next proceed to measure quadrilateral or four-sided figures. All four-sided figures must also have four angles, and the sum of these angles will always be equal to 360°. Squares and oblongs are rectangular figures; all their angles are alike, and therefore each is 90°, the quarter of 360°. The other quadrangular figures are the rhombus, rhomboid, trapezium, and trapezoid.

224. All the angles of a regular polygon are, like its sides, equal, and their value is constant. Any nonagon, for ex-

ample, will always have its adjacent sides making the same angle with each as any other nonagon, irrespective of size, and this angle will never be found in an octagon or decagon. Every polygon has its special angle, so that if only two sides and one angle are given we could construct the whole figure. Practically, however, polygons are never drawn by the measurement of their angles, so we need not give in detail the specific angle of each kind.

225. The measurement of angles enters very largely into trigonometry and land surveying. By means of these measurements we are able to reproduce any irregular right line form, either the size of the original or with any degree of enlargement or diminution. An example of this is given in fig. 51. ABCDEFG is an irregular plot of ground, and HIJKLMN the same plot to a larger scale. To effect this, the original figure must be cut up into any convenient arrangement of triangles, not necessarily those shown in our figure, and these are reproduced, triangle by triangle, starting from the new base line. In our figure, HI is the representative of AB, and whatever angles are observable at the extremities of AB are also drawn at the extremities of HI; angle LHI is, therefore, similar to EAB, and angle LIH is equivalent to ABE. On line HL we proceed to construct a triangle, HLN having angles similar to those of the triangle AEG, and on line LI we draw a triangle, LKI, having its angles agreeing with those of the triangle EBD. We proceed in this matter step by step until the whole figure is constructed.

226. Beginners are sometimes puzzled by the difference drawn between the words "similar" and "equal," where, as in the case of two triangles, the angles are in the two figures the same, these figures are said to be similar. Thus EFG and LMN are similar triangles, though one is evidently much larger than the other; were they identical in size as well, they

would be equal figures. A square on a base of one inch is a similar figure to a square on a base of six inches, but we must find another square also on a base of one inch before we can say that we have a figure equal to the first. In the same way two circles each struck with a radius of three inches are equal circles, while two circles struck with radii of two inches and ten respectively are similar. HIJKLMN is a similar figure to ABCDEFG.

227. On many scales a line of divisions marked "C" or "Cho" may be found; it may be seen, for example, in figs. 33 and 34. This is called the line of chords; it is another method of obtaining angles. To employ it, a curve is struck having a radius equal to the distance 0–60 on the scale, and on this arc the required number of degrees is marked by taking the distance, whatever it may be, along the scale from 0 and then transferring this distance to the curve. When the angle, as is ordinarily the case, has to be drawn from a given point in a given straight line this point is taken as the centre from which the arc is struck, and where the arc touches the straight line becomes the starting-point for measuring the distance upon the curve.

CHAPTER X.

The sector—Principle of its construction—Line of lines—Illustrative examples of its use—Enlargement or reduction in any given proportion—Line of polygons—Illustrations of its use—Description of polygons or multilateral figures—The line of chords—Examples of its use—Cost of the sector—A box of mathematical drawing instruments—Second-hand things—School sets—Cost of various selections of instruments—Long measure—Surveyor's measure—Square measure—Solid measure—Abbreviations—Figuring dimensions on drawings.

228. The sector. This is a very ingenious instrument, and our work would certainly be incomplete if we failed to refer to it, for it is frequently placed in the box of instruments supplied; but at the same time it is rarely used, as other means are generally available for obtaining the various results. Sines, scants, tangents, &c., are readily obtainable by its means, but as these are rarely required in drawing work, the instrument is put aside or only used as a ruler.

229. The sector consists of two equal rulers jointed together at one end. These rulers or legs lie side by side when the instrument is shut up, but they can be opened to any angle with each other, or extended so far that they make a straight line. A sector, then, of six inches will, when fully open, be a foot long, and the outer edges are on one side of the instrument marked with inches, so as to enable it to be

used as a foot-rule. Various scales are marked upon it, but the only ones we need here refer to are those marked "L," "POL," and "C." Fig. 52 is a representation of one side of a sector; it shows two of the scales we have mentioned, and others would be found on the other side.

230. The scale marked "L" is the line of lines. It is used for dividing lines into equal parts, obtaining proportionals, constructing scales, &c. The line of lines is on each half or leg divided into ten primary divisions, and each of these is again divided into ten parts. All measurements taken lengthways on any of the scales are called lateral distances, and all distances taken across from leg to leg are termed transverse. If, now, we want to divide a line three and a half inches long into nine equal parts, we first open the sector until the distance from 9 to 9 is equal to the length of the line. Then from one extremity of the line we set off the distances 8–8, 7–7, 6–6, and so on, and the line will be divided as desired. The proof of the correctness of this will be found in the second problem of the sixth book of Euclid.

231. It is required, again, to find .84 of a line three inches long. To do this we extend the legs of the sector until the compasses with a radius of three inches have their points resting on the two 10's. These primary values, we must mention, may be taken either as units, tens, hundreds, thousands, &c., as we choose, and as the problem before us is to find the eighty-fourth part out of a hundred, we consider the entire line as one hundred parts long. If, now, while keeping the sector open at the same angle, we shift the compass until its points rest on the fourth secondary division on from the eighth primary, we have found a distance which is .84 of the whole line.

232. The fractions need not be decimals; we can as readily

take any others. We will suppose that we want to find $\frac{71}{95}$ of a line, the whole line being two inches long. To work this out we take a distance of two inches by compass and extend the limbs of the sector until the points of the compass rest on the 95 on each side; we then close the compasses until they span the distance between the two 71 points, and this distance we set off from one end of our line; it is the $\frac{71}{95}$ of it. We can in like manner take fractions of fractions. The first line in fig. 53 is divided at B in .43 of its length; the second line, DE, has at F a point $\frac{71}{95}$ from D; while the third or lowest line, GH, is divided at point K into $\frac{2}{3}$ of $\frac{5}{7}$ of its length. This redivision can be carried to any extent. The line GH is first taken and the sector opened until the length of the line spans from 7 to 7. The distance 5–5 is then taken and marked off from G to GI. This point, I, would not really be shown, but we have marked it to facilitate our description. What is really wanted is $\frac{2}{3}$ of GI. The sector is now taken and extended until the distance GI reaches from 3 to 3 on the scale, and then the distance 2 to 2 gives us the required point K. GK is the $\frac{2}{3}$ of $\frac{5}{7}$ of GH.

233. A given line, LM, on a map represents 41 miles, and we desire to make a scale that will be available up to 100 miles. To effect this, we first take the given distance, and open the sector until the extremities of our line agree with the first division beyond the 4 on each side, and then extend them from 10 to 10. This latter distance is the 100 miles required, and we divide this anew into tens, and the last tenth to the left into single miles, so as to make the whole into a practicable scale for measuring any distances in our map.

234. Drawings can, by means of the sector, be reduced or enlarged in any given proportion. If, for example, we desire to reduce a plan in the proportion of 5 to 9, we take any line

in the original drawing, and open the instrument until the ends of the line rest on 9 and 9. We now take the distance between 5 and 5, and this at once gives us the length of the line, the equivalent of the first, in our reduced drawing. We could proceed in like manner with all the lines, first measuring them from 9 to 9 and then from 5 to 5, but practically we should, having once got the proportion between the original and the reproduction, make the two scales, and work from one to the other. These scales would, of course, be made by means of the sector.

235. To find a third proportional to two given lines. Let these lines, say, be as 4 is to 6. We take then laterally along one leg of the sector the distance from 0 to 6, and open the instrument until this distance agrees with 4 and 4. We now take the transverse distance between 6 and 6 and measure it laterally from zero, and we find that it falls upon point 9, a sufficient proof that our work is correct, for a moment's consideration will show us that as 4 is to 6 so is 6 to 9.

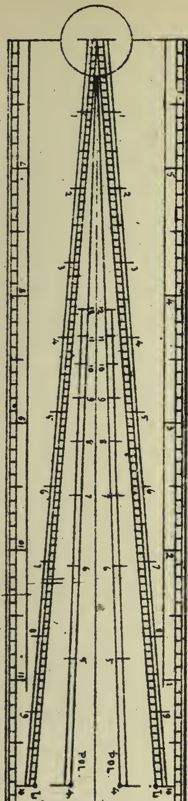
236. Many other examples of the great use of the line of lines might be given, but enough has been said to indicate the mode of procedure, and our readers may readily find other applications of the principle. The true line of lines is the inner one in each case. It will be seen that at each point "L" in our illustration, fig. 52, there are three parallel lines close together; the upper two are merely to enclose spaces in which the divisions of the scale are put, the tenths going a little beyond the outer line, the fifths just reaching it, and the intermediate points only extending from the inner to the middle line. The true line of lines is the inner one, as we have said; it is the only one that really goes to the centre. It is marked at its outer extremity by a small brass nail-head, and is in many instruments ruled in red, while the other two parallel to it are in black. In the same way it is

the inner line again that is the true line of polygons, and this, too, is marked by a brass stud at its outer extremity, and by being ruled in red.

237. We proceed now to see what use may be made of the line marked "POL." This line may be seen in our illustration, fig. 52, nearer the line of junction of the two legs than the line we have hitherto been considering. It will be remembered that the radius of a circle goes six times round its circumference, and the scale is so graduated that if we take any given distance as radius, and adjust it transversely from points 6 and 6, then the distance 5–5 would go just five times round that circle, 9–9 just nine times, and so on. The scale is marked from four to twelve, and in fig. 54 we have drawn a circle, and placed within it figures of four, five, six, seven, and eight equal sides, doing all dividing up of the circumference by means of the sector alone.

238. Though we find the first figure on the line of polygons to be a four, the smallest number of sides that constitutes a polygon (or many-angled figure, as the word means), is ordinarily in geometrical work taken as five. In some old works the triangle is called the trigon, or three-angled figure, and the square a tetragon, or four-angled form; but neither one or other of these could legitimately be called a polygonal or many-angled figure. A polygon may have any number of sides beyond four, and each polygon bears in addition a specific name, indicating what the number of sides is. Thus we have the pentagon, hexagon, heptagon, octagon, nonagon, or decagon, according to whether the figure has five, six, seven, eight, nine, or ten sides.

239. We do not ordinarily go much beyond these numbers in practice, but any one acquainted with the Greek names of the numerals will have no difficulty in naming any special form. The sixteen or six-and-ten-sided figure would be a



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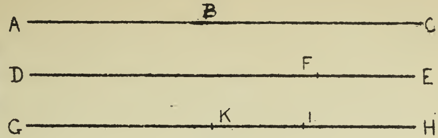

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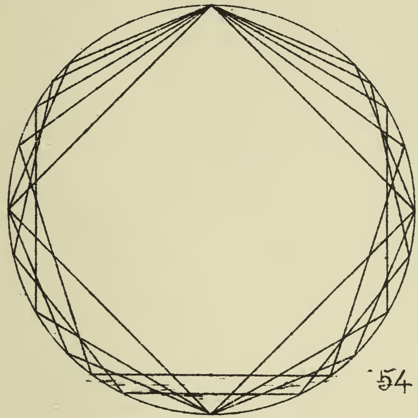

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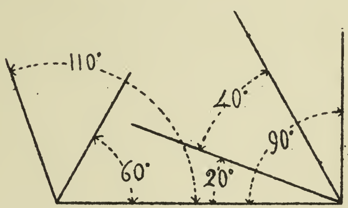

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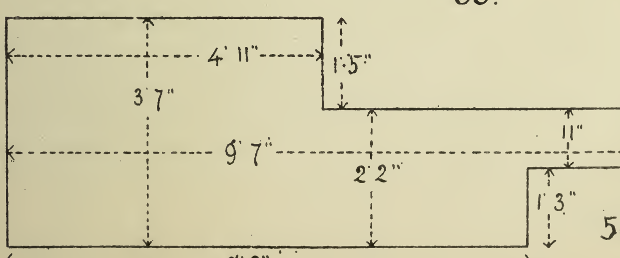


56.

hexadecagon, and the same way of compounding the name would be applied in all cases. Sometimes, where one may not feel quite sure of the real name, or would be afraid of being suspected of affectation in using it, we find the figure spoken of as a polygon of so many sides, sixteen, eighteen, or whatever it may be.

240. Polygons are also termed multilateral figures; the first word, we have seen, means many-angled, and the second signifies many-sided. Either are equally descriptive and appropriate, though general usage has made the former the more familiar term.

241. When a polygon is spoken of, it is always understood to mean a regular polygon, *i.e.*, one having all its sides and all its angles equal. When this is not intended, the figure referred to is distinctly called an irregular polygon; such figures may have their angles equal and their sides unequal, or their sides may be equal but the angles unequal, or both may be unequal.

242. Having described the simple method by which, by means of the sector, we are enabled to draw any polygon up to a dodecagon in any given circle, we now proceed to consider how the converse of this—one side of the polygon being given to construct it—is to be effected. We will suppose that we wish to construct an octagon having sides an inch long. We begin by opening the sector until the points of the compass, open to the required length of side, rest on the corresponding opposite numbers in this case on the 8 and 8, as our figure is to be an octagon. We then take the distance that we find points 6 and 6 apart, and, with this distance as radius, we draw arcs from each extremity of the given side of the polygon as centres. The point at which these arcs intersect is the centre of a circle that will contain the given line the required number of times, the radius of this circle

being the distance from the intersection of the arcs to either end of the given line.

243. We now pass to a consideration of the line marked "C" on the sector, the line of chords. This, like the line of chords on the protractor, is used to determine any given angle by, but it differs somewhat in construction. We will suppose, for the sake of illustration, that we wish to make an angle of 43°. Having drawn a line, and indicated on it the point that is to be the apex of the required angle, and the starting-point of the new line that is to make at this point the required angle with the first line, we draw an arc of any radius from this point as centre, and having one extremity resting on the given line. We now open the sector until the two points of the compass rest on points 60, 60, and then, whatever the transverse measurement between 43 and 43 may be, we take this distance and set it along the arc. The measurement is commenced from the point where the arc touches the first straight line, and wherever the radius cuts the arc we draw a line from that point to the centre from which the arc was struck. The two straight lines will be at the required angle with each other. The work done by the sector may be tested and proved by the protractor.

244. As half degrees are marked on the line of chords on the sector, a little care must be exercised, or, when we think we are taking 43, it may really be only $41\frac{1}{2}$.

245. Sixty is the highest figure given in the sectoral line of chords. When we wish to get an angle of more than 60°, we have to divide the number by two or three, and having obtained the half or the third of it, step the distance twice or thrice along the arc.

246. The line of chords can be used to construct any polygon of which the sides will divide into 360 without remainder. Eight, for instance, is contained just forty-five times in

this number, and eighteen just twenty times; either of these figures, therefore, could be constructed by means of the line of chords, and a little reflection on the part of our readers will enable them to add others to these. As an example of the *modus operandi*, we will consider how an octadecagon would be constructed. On the circle being struck of any required size, the radius is taken, and the legs of the sector shifted until the compass points rest on the two 60 points on either side. As eighteen is contained twenty times in 360, we now place the compass points on 20–20, and this distance is one side of the required polygon. All that now remains is to mark it off carefully eighteen times round the circumference of the circle.

247. The other mathematical lines that are sometimes put on the sector we need not here enter into, since they are for the working out of problems that drawing does not ordinarily have much to do with. We trust that we have nevertheless brought forward enough to make the beginner regard his sector with more respect than he once felt for it; to consider it at least as something more than a jointed foot-rule. The price of a sector, we may just add in conclusion, should be about eighteenpence if of boxwood, or five shillings if made of ivory. The latter are much to be preferred, as the readings are much clearer. Ivory, too, is much harder than boxwood, and where, as in the case of the 60, 60, and other points of the sector, we are often using the same part of the instrument, the less dense character of the wood is a disadvantage.

248. Having now gone through the various instruments in detail that are found in ordinary use, we may devote a few lines to the consideration of what they form in the aggregate; what we understand when we hear a box of mathematical instruments referred to.

249. Two or three very inferior instruments may often be seen fastened together on a piece of cardboard and retailed to the unwary for a shilling or so. Such things cannot possibly be good, and any one who really intends to do any real work should carefully eschew them.

250. Second-hand instruments may at times be procured, but too often their purchase proves no economy; the joints are out of order, screws missing, scales split, or divers other indications that the things are worn out. It is a well-known fact, too, that large numbers of inferior things are made by unscrupulous manufacturers, and then got into the market as second-hand goods. We recall the experience of a friend of ours who once got a note from a pawnbroker, saying that he had several sets of instruments by him, and that he should be glad to dispose of them. They were seen and purchased, a wonderful bargain; but when they were given out to his pupils, he realised too late what an unsatisfactory lot of things had been palmed off on him.

251. Where economy is a consideration, it is better to buy a few good instruments without a case than spend the same money in both case and instruments, as the added cost of the former must make the latter inferior than they otherwise would be. In many circumstances, as at large schools, some means of putting instruments away and keeping those of various owners separate is essential, and some form or other of case largely adds to their preservation and portability. Where a wooden case is too expensive or too bulky, it is often a good plan to wrap the instruments carefully in a piece of wash leather, but pocket cases of thin wood, covered with leather, and having their corners rounded, are inexpensive and very useful, as they contain only the most essential instruments, and in the most portable form.

252. The box most ordinarily used in schools and by be-

ginners generally is about seven inches by four, is made of mahogany or rosewood, fastened by a catch, and contains the following instruments:—Large compass, that can be used as a pair of dividers, and having movable joints for either pencil or pen work, bow pencil and bow pen, ruling pen, and a six-inch rule, having various scales on it, and available as a protractor. Such a box should cost about fifteen shillings to eighteen shillings and sixpence. Wherever electrum is used instead of brass, or ivory instead of boxwood, the cost is considerably increased, and such points as whether the compasses are single or double jointed, good lock and key or no lock at all, and many other details, modify the price in all sorts of ways.

253. It is needless to go through all these details; we will therefore suppose that, having sent off our schoolboy, in the last paragraph, with a suitable box, a friend wishes to know what he is likely to get for the five pounds that he is willing to spend. On reference to a maker's price list, we find that he may have a good walnut and silk-lined case, tumbler lock, and the following electrum instruments:—Double-jointed compasses, lengthening bar, pen and pencil points, double-jointed pencil with bow compasses, good pair of dividers, a set of three spring bows, two drawing pens, a pricker, a knife key and an ivory sector, parallel rule, and protractor. The highest price in this catalogue we note is thirty-five pounds, so it will readily be seen that there is abundant choice. It may be some consolation to those who do not see their way to any great expenditure to learn that really beyond a certain point the cost goes in finish and mountings that are refinements beyond the need of the beginner. The more expensive boxes, too, include colours, Indian-ink, sable brushes, and palette.

254. The novice should, if possible, get some one to advise him what instruments the nature of his work will mostly re-

quire, for though many of the things are equally useful for all, others have a special application. We may safely discard then what is not wanted, and be the better able to procure the essentials.

255. In our next chapter we shall proceed to consider some of the more useful accessories. We conclude by giving some of the more important measures. These should be familiar to all concerned in mathematical work, as the time that is lost in hunting up the information at the moment it is required might often be of some importance. Any one, for example, who could at once set off a scale of miles, furlongs, and chains would have a great advantage over another who had to ransack his bookshelf for the necessary information.

Long Measure.

12 lines	=	1 inch.
12 inches	=	1 foot.
3 feet	=	1 yard.
$5\frac{1}{2}$ yards	=	1 rod, pole, or perch.
40 perches	=	1 furlong.
8 furlongs	=	1 mile.

To these may be added—

4 inches	=	1 hand.
6 feet	=	1 fathom.
3 miles	=	1 league.

In military drawing, 33 inches make 1 pace. In questions in army papers, scales to read paces are often called for.

Surveyor's Measure.

1 link	=	7·92 inches.
100 links or 22 yards	=	1 chain.
80 chains	=	1 mile.

Imperial Square Measure.

144 sq. inches	=	1 sq. foot
9 sq. feet	=	1 sq. yard.
$30\frac{1}{4}$ sq. yards	=	1 sq. perch.
40 sq. perches	=	1 rood.
4 roods	=	1 acre.
640 acres	=	1 sq. mile.

To these may be added—

100,000 sq. links	=	10 sq. chains.
10 sq. chains	=	1 acre.
$272\frac{1}{2}$ sq. feet	=	1 rod of brick-work.

Square measure is used for all measurements of surface, all superficial areas, anything like flooring, paving, or meadow land, that has both length and breadth.

Solid Measure.

1728 cubic inches	=	1 cubic foot.
27 cubic feet	=	1 cubic yard.
8 cubic yards	=	1 cubic fathom.

This measure is used for things that have length, breadth, and thickness or depth, as stone, timber, excavations in earth, and the like.

Most of the abbreviations used are sufficiently clear to need no explanation, such as in. for inch, yd. for yard, and m. for mile; but the signs ordinarily used by architects and engineers for feet and inches are not so self-evident. To mark these, a single dash is put after a number when it stands for feet, and two dashes when inches are intended. One foot six inches would be represented as follows—1′ 6″. A single dash after a figure also means minutes, but the general circumstances of the case will always show which is meant, and minutes are rarely, if ever, standing alone; they are always added after some number of degrees. Thirty-seven degrees thirty minutes would be marked as 37° 30′.

256. When several angles start from one point, and there is some little possibility of confusion arising, arcs of different radius join the various pairs of lines, and in a break of the arc the number of degrees is marked. Fig. 55 is an illustration of this.

257. Where dimensions are marked on a drawing, unless the distance is very short, the distance from point to point is not only expressed by the figures placed between these points, but a dotted line in addition joins the two, and an arrow-head at each end marks the termination. This may be placed at any point where it gives the necessary information. In an oblong, for instance, the lines marking length and breadth need not necessarily start from the middle of each side: if printing comes there, they may be above or below, or to left or to right of it, or even outside the whole thing, so long as they truly indicate the measurement from point to point that they join. In fig. 56 we have represented the various ways in which these measurements, &c., are shown. In many drawings the measurements will be found by taking them by compass and then applying them to scale, as a great many

dotted lines across a drawing would tend to confusion; but in detail and working drawings it is often a convenience to have the actual distances, so that the workman into whose hand they are put is at once able to see what the size of the various parts should be.

CHAPTER XI.

Paper—Best sizes to get—Cost—Hand or machine-made paper—Cartridge paper — Sizes made — Mounted papers — Straining paper—Causes of failure—Straining paper on panelled boards—Drawing pins—Care in re-pinning paper down—Moisture injurious to paper —How to mount drawings — Mounting boards — Over-mounts—Under-mounts — Tracing paper — Papier végétal — Directions for tracing—Tracing by leaded paper—Tracing by a sheet of glass—Hand-paper.

258. We propose now to give some little attention to points that, though subordinate to our subject, are nevertheless of some importance; for no chain, it must be borne in mind, is stronger than its weakest link, and the best instruments procurable for money do not have a fair chance unless the paper, the Indian-ink, and all the other accessories are good of their kind too.

259. The paper we are to use may naturally engage our first consideration. There are so many various sizes and thicknesses of paper made, that it is a somewhat difficult task to select any particular make for special approval, as all have their merits. The first great consideration is the size of our drawing, and we must next consider whether we propose to be content with an outline or whether we aspire to a coloured drawing. A rather smooth paper is the better if the work is to be only inked-in, and a rather rougher texture if we propose to colour on it. The happy medium is as usual the safer course. The rough texture used by some artists for watercolours,

though it takes the colour well and makes very effective work, is too coarse for the necessary drawing that must first be done. The very smooth paper known as hot-pressed is, on the other hand, almost too glossy.

260. The larger sized papers are the stouter in make and ordinarily the rougher in surface, but those known as antiquarian, double elephant, atlas, and imperial, meet with very general acceptance. The same size of paper may often be met with of various textures and thicknesses; thus imperial, for example, is made to weighthirty po unds to the ream, or ninety, or one hundred and forty, and costs seven, nine, or fourteen shillings the quire, according to its substance. All these papers, and the others used by artists and draughtsmen, are considerably cheaper in proportion when a ream is purchased, and many dealers make a decided difference when even five quires are taken. A shilling per quire would probably come off all the prices we have quoted if the order amounted to five quires. All really good drawings are made on hand-made paper, as the surface is much better; it is also whiter and freer from blemishes of various kinds. Machine-made paper, or cartridge-paper, as it is generally called, is much cheaper than hand-made, and is really sufficiently good for a great many purposes. It can also be had in much larger pieces than the hand-made: a piece one hundred yards long can be had if we wish. Though this will be more than sufficient probably for anything the beginner may attempt, it is a great advantage to be able to, at all events, have as large a piece as we want. Cartridge-paper is, for this reason, and its cheapness, much used for diagrams. The surface is very good for outline work, and it takes colour fairly well. It is made in royal, imperial, and double elephant sizes, and one side is always rougher than the other. The smooth side is, under most circumstances, the best to use.

261. The sizes made by various makers, even when called by the same name, vary a little, but the following dimensions are in any case right within an inch or two, and will therefore be a sufficient guide. Demy is 20 inches by 15; medium, 22 by 17; royal, 24 by 19; super-royal, 27 by 19; imperial, 30 by 22; colombier, 34 by 33; atlas, 34 by 26; double elephant, 40 by 26; and antiquarian, 53 by 31. The prices range from two shillings per quire for the smallest size to sixty shillings per quire for the largest.

262. Where drawings are of considerable size and exposed to a heavy risk of wear and tear, this wearing and tearing is prevented by using mounted paper. Cotton, a material called union, and brown holland, are the substances generally used as mounts. The cost is that of the paper, plus the mount, and the labour of mounting it, but it is often a wiser economy to do one drawing on mounted paper, than to have to repeat the labour and make good the ravages of the tooth of time and the sharper perils that arise from the handling of careless workmen, or the breezes that play around the elevated positions where it may be necessary to consult the work.

263. When a drawing is of considerable size and likely to be some time in hand, it is a good plan to strain the paper. It is much easier, too, to colour on a strained surface, as the cockling up of the paper is avoided. To strain a sheet of paper successfully the following points should be observed. The paper must be first thoroughly damped with clean water, sponged equally all over it on the opposite side to that which we propose to use. This damping should not be excessive, and the surface of the paper should be as gently treated as practicable, or its texture may be damaged sufficiently to spoil fine inking. The paper must be weighted at the corners if it shows signs of wanting to roll up. As soon as the sheet has absorbed the water, the shining appearance will change

into a dull and lustreless one, and the paper is then ready for fastening down. The paper must be turned over and placed with its damper face on the board, and a straight-edge or T square placed parallel to one edge after the other and about half an inch from it. This outer strip is then turned up against the ruler and rubbed with glue, moistened in hot water, or strong fluid gum specially prepared, the ordinary gum being too thin and weak for the purpose. The edge is then turned down again on the board, and when all four sides have been thus treated, a hand must be put to each opposite edge, and the paper very gently pulled outwards each way, the two long sides being first treated in this manner. A smooth knife-handle or pencil should then be rubbed well along each edge, so as to ensure the adherence of the paper to the board. We have ourselves strained many a dozen sheets, and very rarely had a failure; we have often used good strong paste, but in this case both sides should be damped, as the paste takes longer to dry. The idea directing the operations is that the paper being damped will stretch; that while thus stretched it should be fastened securely down, and that the fastened edges should be thoroughly dry before the central part begins to contract. If all has gone well, the paper will, in two or three hours' time, present a beautifully level surface.

264. The following causes of failure should be guarded against. The paper should not be fastened down until it has absorbed all the water, and is no longer expanding. Anything like a pool in one place should be avoided, as there will else, when dry, be an unsightly water-mark. The middle part should not dry too rapidly; if it dries before the edges, it will tear them up; in warm weather a slight second damping may be given to the whole sheet, except the edges, about half an hour after the fastening down. Until the whole

thing is thoroughly dry the board should not be moved from a horizontal position. Any attempt to hasten matters by putting the board near a fire generally courts failure. While the paper is straining and drying, it should be placed in a place where it will be free from dust. Anything of this sort falling on it may sully and roughen the surface, and we cannot avoid this by placing anything over it, as this would hinder the drying; and if brown paper or printed material like newspaper were used, they would themselves probably stain the sheet while in its damp and receptive state.

265. When all is ready for use, a line should be drawn all round, just clear of the gummed, glued, or pasted part. This line marks the limit to which it is safe to go in the drawing, as the sheet has to be cut off clear of the fastened edges, and any part of the drawing that came on them would be sacrificed. All outside of this line is very useful for trying the ruling pen or the colours on, as we have already pointed out when referring to the use of the pen.

266. The use of the T square in straining not only gives at once a strip ready for the adhesive, but it also prevents this adhesive going farther in from the edge than it should do. It is very provoking when a drawing comes to be taken off the board to find that at one place on its edge the gum or paste has spread too far inwards. This means that a new cut must be taken, another inch, perhaps, all the way along must come off, and then, to make matters symmetrical, an inch more must come off all the way from the opposite edge.

267. Before putting the damp paper down at all for straining, we should be careful to see that the board is quite clean and free from dust. Dust is a great enemy to the draughtsman; it gets on the set-square, and then the drawing is soiled; it gets on the paper, and the lines are broken; it gets into the Indian-ink, and the pen gets clogged. It is a

nuisance that cannot too rigidly be guarded against; we would, in fact, almost go so far as to class the duster among the necessary instruments of the mathematical draughtsman.

268. When a drawing is finished and cut off, the edges that remain all round on the board should be removed before another piece of paper is fastened down. The board should be placed in a horizontal position, and a little warm water trickled all along these edges from a sponge. In a quarter of an hour or so they should come up readily. If several strips are allowed to accumulate one over the other, they hinder the proper working of the square, and are much more difficult to remove. We have more than once seen a student working hard with a chisel, damaging at once his temper and his board, in the laboured attempt to remove a mass of old material that might much more readily have been dealt with if attended to each time the board was used.

269. Panel boards were at one time a good deal used, but they appear to have now gone a good deal out of favour; they are rather expensive. We refer to them now because they afforded a very ready way of straining sheets of paper with the use of any adhesive. Fig. 57 will give an idea of the construction; it will be seen that the board is in two parts—a central panel and a frame fitting tightly all round it. To use it for straining we should place the damped sheet of paper on the panel, and then press the frame on all round and hold it in position by two little catches behind. The paper must always be a little larger than the panel, or there would be no grip; but it will readily be seen that we are tied down to one size of paper. On an ordinary board we can fix either a small or a large piece of paper at our option, but the panel board gives us no such choice; the size of the panel rigidly governs the size of the paper.

270. As some guide to cost, we will quote from a trade

catalogue before us the prices of two or three boards, the first price given being for an ordinary clamped board, and the second for the panelled. A quarter imperial, or $13 \times 9\frac{1}{2}$ inch board, is 1s. 3d. or 1s. 10d.; a royal, or 25×20 inch board, is 4s. or 5s.; and a colombier, or 36×25 inch board, is 7s. 9d. and 9s. These prices are, of course, to be taken only as an approximation; other makers might be either slightly cheaper or dearer than those given.

271. For small drawings, and those that will not be long in hand, drawing pins make a very good fastening. These are made of various sizes, and vary in price from fourpence to a shilling a dozen. Three illustrations of them are given in fig. 58. The first and second have heads that readily allow the T square to pass over them, while the milled edge of the third makes it more easy to get out than the others. Practically there is not much difference in the using, for the T square rarely goes so near the top or bottom of the drawing that the milled edge of No. 3 becomes any real check, while the difficulty of getting hold of the others is got over by inserting the knife blade under them.

272. As drawing pins when loose do not make at all good pocket companions with pencils, keys, &c., as one realises on diving the fingers suddenly into one's pockets for anything, we may just indicate in fig. 59 the way that we have found amply efficacious and protective both of our own feelings and the points of the pins. We cut as broad a ring as we find necessary off a common wine-bottle cork; into this the points readily penetrate and do not draw out again, and the pins may in this way be carried safely for days or weeks, and will always be at hand when wanted.

273. Where the size of the board will allow it, the papers should not always be pinned down about the same places, or

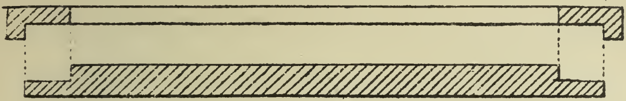
else the board gets so full of punctures there that presently the pins fail to hold.

274. In buying pins, only the more solid makes should be taken. Some kinds have the upper and lower points screwed together, but the screw is so weak that the heads come off on a slight provocation. By taking an altogether disproportionate amount of trouble we can sometimes screw them on again, but the repair is only temporary. As the points, when headless, cannot very well be extracted from the board, it is best to at once hammer them in flush with the surface.

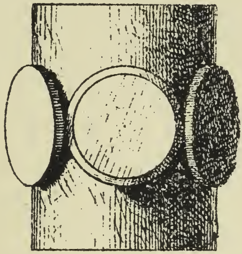
275. When a drawing has been pinned down and then removed from the board before it is finished, great care must be exercised in pinning it down again, or the work when resumed will not be "true" with that already done. The paper must be placed loosely on the board and the T square placed in position. The paper must now be gently moved about until one of its lines agrees with the edge of the T square. We may now fasten it down, feeling secure that the lines yet to be drawn will be in harmony with those already there. This seems, when mentioned, an almost superfluous caution, but the idea does not occur to every one; we have often seen beginners evidently under the impression that they have merely to pin the paper down and all will be right. The result does not justify their confidence.

276. A drawing should never be attempted on damp paper. At some seasons of the year the moisture in the air affects paper a good deal, and a sheet that is to all appearance dry will steam when held near a fire. Besides the difference in comfort in working on a dull sodden sort of surface and one that is pleasantly crisp, the work is actually hindered by any dampness, as the india-rubber cuts up the surface, and the ink lines have a blurred look instead of the sharpness of definition that is so desirable.

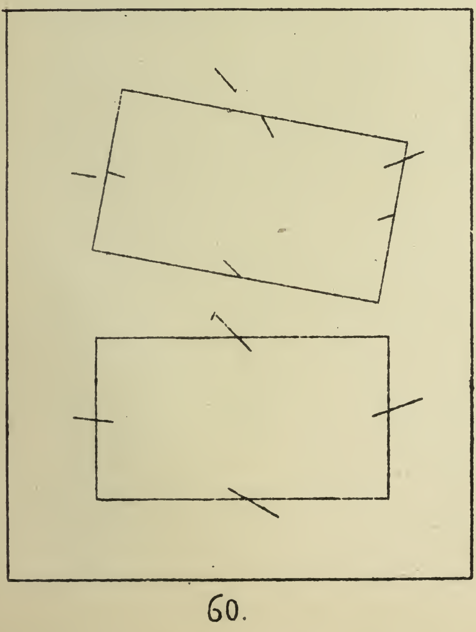
57.



58.



59.



60.

61.

277. Drawings sometimes require to be mounted, either for exhibition purposes or to preserve them. Cardboard mounts, or linen or canvas, are the materials generally used. Really good drawings may be mounted so well and so cheaply by those whose business it is, that we should strongly advise that anything of value should be handed over to them, but many things of less importance are nevertheless the better for being on a mount, and a few directions will be useful.

278. In mounting a drawing of any considerable size, a good stiff sheet of cardboard should be used, what is called four-sheet or six-sheet being the best. These mounting boards are generally sold in two qualities, best and seconds. The latter have some slight blemish or speck, but practically the drawing when it is stuck down often covers this. The difference in cost is very considerable. A dozen four-sheet mounts, imperial size, first quality, will cost about 9s. 9d; the same thing in second quality will cost 5s. 4d. only, and it takes a keen eye to see any difference in them except in price.

279. Having got our mount, we now proceed to trim our drawing, if it is to be over-mounted, or to cut the necessary opening in the mount itself if the work is to be under-mounted. In the first case, the drawing is stuck on the mount as in an ordinary carte de visite as we receive it from the photographers; in the second case, it is behind the mount, and shows through the opening cut in the card in the same way that the carte does when we put it in the opening prepared for its reception in our album.

280. The front or over-mount is the easier to do, but the less effective when done. The mode of procedure is as follows:—Having cut the edges of our drawing neatly, we place it either by eye or compasses in the centre of the mounting-board, and then make a slight pencil mark near the top corners. The drawing is now placed face downwards on

a sheet of paper, and pasted well over. It will probably at once begin to curl and cockle up, but a slight weight here and there will prevent any harm being done. A sufficient time must be allowed to elapse to make sure that the drawing has stretched as far as it will; thick paper will take considerably longer than thin. When the paper is thoroughly limp, it must be gently taken up and its two top corners placed to the marks on the mounting-board, and then the whole with a soft cloth pressed down to the mount. If the edges are pressed tightly first, large air-bladders will remain in the middle; the pressing, therefore, should begin in the middle, and a series of gentle dabbings gradually working outwards will force the air before them. Even then the surface may not look quite even, but all probably will come right as the whole dries. Gum is not a good material to use, as any that is squeezed out at the margins has an unpleasant shine that betrays it.

281. In under-mounting we cut an opening of the necessary size in the centre of the mount, place the drawing on the table, and the cut mount loosely on it. We now shift the mount about until we get the lines of the drawing true with its edges, and then with a certain dexterous knack, that comes by practice, we slip a hand under each side, and lift up both mount and drawing without shifting them on each other, and turn them upside down. As there may have been, after all, a slight movement, it is a very good plan to take either a couple of wafers, or, better still, an inch or so of the ready gummed paper that we find round the edge of a sheet of postage stamps, and fasten the drawing and mount roughly together in two or three points. We are now enabled to turn our work over again the proper side upwards, and note if the turning upside down had really caused any shifting of the drawing on the mount. If it has, we must simply try

again; but if not, the two or three temporary points of attachment can remain, as they will be covered over by the long narrow strip that we now fasten each edge of the drawing down with.

282. Drawings are frequently copied or multiplied by means of various methods of tracing. Tracing-paper is sufficiently thin and transparent to allow the lines of a drawing placed beneath it to show through; where the drawing will be exposed to rough handling, durability is better attained by using tracing-cloth. Either of these articles are very cheap and very readily procurable. The French tracing-paper, or *papier végétal,* is rendered transparent in the process of manufacture, and not, as in the ordinary kind, by an after preparation of oil. It has a greater transparency, a surface that will take colour well, and as no oil enters into its manufacture, it has neither the rank smell that is so disagreeable to some persons in the ordinary make, nor can there be any possible injury to drawings on which it is placed.

283. The tracing-paper should be held securely either by weights or pins while a drawing is in process of reproduction, or a slight and undetected movement of one or the other may throw all the work out. As it is often difficult to see how the work is going on, and whether all the lines of the original have been gone over, it is a considerable assistance to slip a sheet of white paper carefully between the drawing and the tracing-paper, when all the lines on the latter become at once clearly visible, and any omission readily noted.

284. When we for any reason remove a piece of tracing-paper temporarily, and then wish to replace it accurately, it is a good plan to draw a line or two, in the way we have indicated in fig. 60, on both tracing and original before it is removed. If the lines on the tracing-paper and the drawing "read into" each other, the old position is restored. In one

of our pieces of paper in the illustration we see it correctly replaced, and in the other incorrectly. It may be said, Why take all this trouble when the lines on the work itself are there as a guide? But in a complex outline-drawing it is often some little trouble to get matters straight if once moved, and in a shaded drawing it is very difficult sometimes to see them at all.

285. Drawings may be copied by first placing a sheet of clean paper down, then on this another sheet rubbed over with black lead, the leaded side being turned to the first paper, and then over all the drawing to be transferred. All these should be securely pinned down together, and then, by means of a lead pencil or the tracer—a blunt metal or agate point fixed in a handle, and supplied in some boxes of instruments—all the lines of the original are gone over with a sufficient pressure to transfer them, by means of the black lead, on to the clean paper beneath. Two or three copies can be made at one operation by arranged clean and black-leaded papers alternately under the drawing to be copied. For a small piece of blackened paper, a rubbing over with a soft pencil is sufficient; but for larger pieces it is a saving of time to avail oneself of the ordinary black lead that all households contain squares of for domestic use.

286. A large sheet of glass is another admirable means of copying. Any one may readily test this by placing a piece of clean paper on a drawing, and then holding both against the window-pane.

287. We cannot close our remarks on paper without briefly referring to one homely member of the family—the waste piece on which we put, or should put, our hands. There is always a certain degree of exhalation from the pores of the skin, and a piece of hand paper, regularly used, will often save the paper from growing unworkable when we come to

ink or colour. This hand paper should be often changed; a black and grimy piece, while it testifies to how much the drawing has escaped, does not in the same degree bear witness to the cleanliness of the person using it. The hand paper should not be used to try ink or colours on, as there is a great risk that they may presently be transferred to the drawing from it.

CHAPTER XII.

Pencils—Best kinds to use—How pencils should be cut—Putting the pencil in the mouth—Knife and file—Pocket pencil—India-rubber—Care in pencilling—"Scrolling out" lines—Bottle-rubber—Vulcanised rubber — Ink-eraser—India-rubber never to be held in hand when not in use—How to cut India-rubber—Knife erasures to be avoided—Stale bread—Indian-ink—How to select it—How to prepare it for use—Liquid ink—Nests of saucers—Common ink to be avoided—Common pen and crowquill—Printing—How to space out lettering—Useful alphabets—Lettering square—Arbitrary signs in topographical work—All drawings to be signed and dated—Stencilling—Colouring—Ox-gall—Recognised colours for various materials — Prepared liquid colours — Brushes required—Great cleanliness necessary—How to choose a brush—Camel hairs—Sables—Sizes and prices—Closing remarks.

288. The pencils that are used in mathematical drawing call for our consideration, as they affect the quality of the work. If the pencil has too soft a character, it makes lines that are deficient of the necessary clearness, and the surplus black lead rubs and soils the drawing. It is difficult, too, to ink-in satisfactorily when the pencilling is strong and heavy, for then the lines are already almost as dark as ink lines would be. When, on the other hand, too hard a pencil is used, it makes a groove in the paper; and this, again, is fatal to good inking. For ordinary work a pencil of moderate hardness should be taken, either an F or H, or HH. Besides the greater clearness and lightness of the lines that such

pencils would make, they also keep their points much better and for a longer time than the softer kinds; this is itself a great advantage, as it is a heavy drawback to be obliged to stop often to renew the points.

289. The pencils of one particular maker should be adhered to if they give satisfaction, as the standard of hardness or the reverse varies with different men. The HB of Rowney is about equal to the F of Gilbert, and the HB of the latter is about equivalent to the B of the former, and the same variation may be noticed with other makers. Each has a consistently graduated scale of his own, but the similar letters of different men do not represent identical values. As the colours of the wood vary as well, a further difficulty arises, as we soon find when we pick up a pencil that from its colour we take to be an H, and then find it to be the B or BB of some other maker.

290. The way the pencil is cut is a point not beneath our notice. Many draughtsmen prefer what is called a chisel point, as they allege that it keeps longer in serviceable order without attention than any other. It is represented in the first illustration in fig. 61. Our view is a front one. Had we shown a side view of it, the appearance would be very like that of the centre figure; it is, in fact, very like the end of a chisel, broad one way and narrow the other. We cannot ourselves say that we prefer this form. It requires holding always in one position, and it is not well adapted for marking a point. On the whole, we think that the central figure represents the most useful form, the wood cut equally all round, and the lead brought to the form of an acutely pointed cone. The wood should be cut some distance up, so that the view of the point is not obstructed when the pencil is applied to a ruler. The third figure represents what to avoid. Instead of the gently tapering form of the central figure, the cedar is

gashed irregularly, and the lead, being for some distance without the support of the wood, breaks off directly any pressure is laid on it.

291. Some beginners have a great fancy for biting and chewing the uncut end of the pencil; the habit can scarcely be defended, though perhaps one could scarcely point out that it was actually injurious to work; but the habit of putting the lead end in the mouth is distinctly objectionable. The theory is that it enables one to make blacker marks, but if the pencil in use does not give sufficient strength, it should be changed for one that will.

292. A combination of knife and file is often placed in the instrument box, and either alone would be very useful. A sharp knife is a very valuable auxiliary; many a pencil is cut half away for want of it, as a dull blade needs undue pressure, and the lead under these circumstances keeps breaking off. When a good point has once been made, a piece of sandpaper or a fine file will be found very useful, as a gentle rubbing on either of these keeps it in good workable condition. Our objection to the combination of the two arises from the fact that one can scarcely with comfort use more than one of them. If we chose to ignore the file and consider it merely as the handle of the knife, we can do so; or if we choose to use the file and let the knife alone, we have reason equally on our side; but in a thing necessitating so much cleanliness as drawing, it hardly seems well to rub the file well over with lead and then grasp it as a knife-handle.

293. There is much more command over a long pencil than a short one. When it has got cut down to about three inches long, it should be put on the retired list or fitted in a porte-crayon. These short bits are very useful as pocket-pencils for jotting down memoranda, or they may be pared down for use in the compasses.

294. The owner of a convenient little piece of pocket-pencil may well be excused if he shows a slight reluctance to lend it. It is not the intrinsic value of it, for on that ground the quarter of a pencil that cost twopence when new can hardly be highly prized; but this very valuelessness of it makes the borrower careless about returning it. It is put down and forgotten, and an hour afterwards, when we are far, perhaps, from our base of supplies, we feel a pressing need, and lose a valuable memorandum for the want of it.

295. Pencils naturally in turn suggest india-rubber. Where a drawing has to be coloured it should undergo as little rubbing as possible, and a little judgment in the pencilling-in will often save a great deal of this. Lines should not be recklessly carried on far beyond their true terminations, and very often a mere mark at the commencement of a line will be sufficient guide. In drawing the plan of a staircase, for instance, we may, when we have marked in the lines of the sides and of the top and bottom steps, merely make a pencil tick at the right places for all the other steps, and then at once draw them in ink. Any error made in the inking is fatal, so that any inking-in without preliminary pencilling requires to be done very discreetly.

296. The need for the india-rubber becomes much less when care has been taken all along to keep the drawing as clean as possible. The use of hand-paper, and of pieces pinned over any part not being worked on, will greatly lessen the labour of cleaning the drawing up.

297. When a slight mistake is made in the pencilling-in, it is better just to "scroll it out," as it is termed—*i.e.*, run a waved pencil line along it to show that it is an error—than to use the india-rubber. This latter will often obliterate more than is wanted.

298. Native or bottle rubber is the best to use, as it does

not disturb the surface of the paper so much as any other, but vulcanised rubber may be employed where no tinting has to follow. The ink-eraser ordinarily cuts up the paper too much to make one willing to commend it. With ordinary care no line need be drawn that native rubber will not remove if necessary. This native rubber is sold by weight; the price fluctuates a good deal. It is cut up into convenient pieces and sold under the name of the number; thus 60 rubber means that one gets that number in a pound weight. In 40 rubber the pieces are of course larger, as there are fewer of them to make up the weight.

299. That which has to clean the drawing should itself be clean. It should not be allowed to stand on a table and gather dust; above all things, it should not be held in the hand, as the moisture of the skin affects it very injuriously. In cold weather it is often over hard and rigid for comfortable use, but ten minutes in the waistcoat pocket will remedy this.

300. When a piece of india-rubber has got so dirty at the edges that it soils rather than cleans the paper, it need not too hastily be discarded, as all that is required is a new rubbing surface. A slight slicing all round will give us as good as a new piece. It is difficult to cut, but if the blade of the knife be first dipped in water it will go through much more readily. Care must be taken to see that the india-rubber is dry before it is applied to the drawing.

301. Wrong lines should not, if possible, be taken out with the knife. Even a too lavish use of the rubber betrays itself when colour is applied, and the action of the knife, whether we ink or colour over the place where it has been used, is ordinarily still more conspicuous.

302. Stale bread makes an excellent means of cleaning up a drawing. It will hardly remove pencil lines of any strength,

but it clears up the general surface of the paper beautifully. Crust should be avoided, as it may dent and scratch the paper when rubbed on it, and great care should be exercised that no particle of butter or anything of that sort should be on the bread. The knife that cuts it must likewise be above suspicion. The crumbs make rather a mess; they should be carefully collected, or they get under the paper, into the ink and in other ways prove a nuisance.

303. Good ruling-pens and compasses are of little use unless the ink proves itself good too. The best ink should, when rubbed, have a soft pasty feel; draughtsmen often try it, when choosing a piece, by rubbing it on their thumb-nail, and if it gives a granular sensation it is at once discarded. It ought not to settle at all in water. Though ordinarily called Indian-ink, we draw our supplies from China. A good deal is, no doubt, made nearer home than this, but the best is that of the Celestial Empire. In ordering a good large quantity we often get it in the original boxes.

304. In preparing ink for use one or two points deserve our consideration. A small quantity of water, three or four drops, should be first dropped on the slab, and then the ink gently ground; more water can be added by degrees. Warm water is better than cold, as the ink rubs more readily. The sides of the stick of ink should be as little wet as possible, or they will chip into the slab; for this reason the ink should be rubbed into water that has been put into the slab by a brush; the ink itself should not supply the needful supply of moisture by being dipped into the cup or glass. This dipping wets far more of the ink than is at all desirable, and as it afterwards drys it cracks. After a rubbing the ink should not be put on the table even temporarily, or some set-square or ruler will presently bear testimony on the drawing to the fact. It should at once be dried and put away.

305. Indian-ink is an exceedingly quick dryer; almost as soon as a line has been ruled the T square may be fearlessly passed over it. This is a great advantage, as no time is lost in waiting. Various preparations of liquid ink are made, but they cannot be commended. The most satisfactory plan is to mix the ink afresh every day, but "nests" of saucers are readily procurable, and their use saves a great deal of trouble. The form of them is somewhat like that of the common saucer, but they have a much thicker rim, and one can be placed on another, or half-a-dozen on each other, if need be. The junction is air-tight, and any ink or colour that is covered over neither evaporates nor contracts dust. Ink rubbed in one of these and covered over will keep in good working condition for a long time. These saucers are sold in a nest or set of six, the cost of such a set being about two shillings. If either ink or colours at any time refuse to work kindly owing to greasiness of the paper, a small quantity of ox-gall mixed with them will at once remedy matters. A preparation of this can readily be procured at any artists' colourman's.

306. Common ink should not be used with mathematical instruments. It cannot be tinted over, it takes a long time to dry, and, worst of all, it corrodes and deteriorates the nibs. It should never appear on any drawing worked in Indian-ink: the common ink has a bluish tinge in its blackness, the other is distinctly brownish, and the one will always look badly when placed with the other. No measurements should be written in with it, no printing done with it.

307. A common pen is often necessary to draw in little details, to figure the dimensions, do printing with, and so on. What is termed a crowquill is sometimes recommended, but they are very weak and unsatisfactory things, and an ordinary fine-nibbed pen, in an ordinary holder that one can handle firmly and comfortably, is far preferable.

308. Printing is a thing that the beginner will do well to practise a good deal, for many a good drawing is spoilt by bad printing. The forms of lettering are not very numerous, but in using them a due consistency should be observed. Even the novice would hardly print in the necessary headings, &c., to a classic design in Gothic text. As a rule, the plainer the printing the better.

Where two or three lines of varying length, as

WEST ELEVATION,

CHURCH OF ST. JOHN THE EVANGELIST, CARRINGTON PARVA,

YORKSHIRE,

are put one under the other, as shown above, an upright line should be lightly drawn in the centre of the space the printing is to occupy, while double lines are drawn as guides for the tops and bottoms of the letters. The more important words in any printing should receive larger letters, and a good clear space should always be left between the successive lines.

309. To set the words out with due regard to symmetry the letters in each line must be counted, and a distance equal to a letter included for the space between each of the words. This number must then be halved, and the necessary number of dots marked off on each side of the upright line. Equal distances between the dots should be allowed, for though some letters, like W or M, are wider than the average, others, like I or J, take less space. These equal distances may very conveniently be taken off by means of a scale that reads to the edge being applied to the line. By using the scale we can see at once, by counting the divisions, how far the text will stretch, and if the distance appears too much or too little,

another scale can be tried. This is better than marking off a number of divisions by the eye, and then finding them after all too far-stretching or too cramped, and having to renew them once or twice.

310. If we take the first line of our illustrative example, we shall find that "west elevation" contains thirteen letters, and a space between the words; fourteen divisions then are wanted, seven on either side of the upright line. In the second line we find that there are forty-two letters and seven spaces. This represents forty-nine parts. If we halve this number, we shall find that there will be a letter in the middle, and twenty-four letters or spaces on each side. The A in Evangelist is the letter that comes on the upright line. The name of the county contains nine letters, the central upright will therefore pass through the S. This general indication of the positions of the different letters being obtained, each should be then pencilled-in. The divisions will have given the required balance and approximate position; beyond this they must not be too rigidly adhered to; we may safely encroach on the space allotted to I, as the general average will bring all right as a whole.

311. This spacing out and sketching of the letters may be done near the edge of a piece of waste paper. This may then be applied to the lines ruled on the drawing, and the forms at once marked off in their proper position.

312. A modification of the set-square has been devised, and called the lettering square. This gives the slopes for the slanting lines of the W, A, M, V, Z, &c.; but, ingenious as it is, it would rarely be much help to the beginner. So many letters like B, C, D, G, and J have curves in them, that we cannot but repeat our advice, and strongly commend the persistent practice of hand-printing. A or W, with all their lines carefully ruled, may look very well; but if S, the great

test letter of one's handiwork, is abominably bad, the total cannot be considered a success.

313. All printing upon the actual drawing should be left until the last thing, and care must be exercised, when the work is in colour, in drawing the guide-lines. They should be just dark enough to be visible, as stronger lines would require more rubbing to clean them out, and this rubbing often pales the tints, and leaves an unsightly whitish streak.

314. It will probably save our readers some little trouble in hunting up good examples of letters if we here place before them some of the varieties that will be found most useful.

1.

A B C D E F G H I J K L M N
O P Q R S T U V W X Y Z

2.

A B C D E F G H I J K L M N
O P Q R S T U V W X Y Z

3.

A B C D E F G H I J K L M N O P Q
R S T U V W X Y Z

4.

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z

5.

A B C D E F G H I J K L M N O
P Q R S T U V W X Y Z

6.

A B C D E F G H I J K L M N O P Q
R S T U V W X Y Z

7.

a b c d e f g h i j k l m n o p q r s t u v w x y z

8.

A B C D E F G H I J K L
M N O P Q R S T U V
W X Y Z

9.

a b c d e f g h i j k l m n o p q r

s t u v w x y z

10.

A B C D E F G H I J K

L M N O P Q R S T U

V W X Y Z

11.

a b c d e f g h i j k l m n o p q r

s t u v w x y z

315. The first alphabet we have given is the form one is most accustomed to, but the difference in thickness in different parts of each letter is rather difficult to deal with in hand-work. The second alphabet is for this reason preferable, and it is also more distinctly legible. This kind of lettering is by architects and engineers called block-letter. Though ordinarily erect, it is sometimes, as in the third example, thrown obliquely. The effect of this last is very good when it is well done, but beginners will find No. 2 easier, as the slanting letters look very unsatisfactory unless all slant equally; and this, at the hands of the novice, they are very likely not to do. In the fourth alphabet, the letters have a little "heading and tailing," but to our mind the bold simplicity of No. 2 is to be preferred. In No. 5 we get the same bold type again, but the letters are much thinner in line. They could be used in all but the most important parts of the work, and will, perhaps, be found the most useful of all our examples.

316. While engineers ordinarily choose before every other consideration the most legible alphabets, and very rightly so, for the lettering of their triumphs of nineteenth century utilitarianism, the architect, more embued with the spirit of the past, revives the beauties of bygone centuries in his work, and very consistently uses alphabets in harmony with it. The remaining examples are Gothic or mediæval in character. Nos. 6 and 7 would be most useful ordinarily, but where greater emphasis is required, Nos. 8 and 9 would be employed. Where we desire to make the lettering bold and conspicuous, and yet prevent it from looking over-heavy, the alphabets numbered 10 and 11 might advantageously be selected, though the doubling of the lines adds very considerably both to the labour and the time required.

317. A very rich effect may be produced by sketching the

letters like those in the alphabets 10 and 11, and then filling in the light parts of each with blue or gold or crimson.

318. Many other alphabets might have been illustrated, but those we have given are the kinds likely to be most generally useful. Many professional draughtsmen are as individual in their lettering as in their work, but the beginner must be content for a while to stand upon the ancient paths and keep to the well-beaten track. The eccentricities of genius have a charm that is somehow lacking in the vagaries of ignorance.

319. The common writing-pen must be used for all marking-in of dimensions. We sometimes see the ruling-pen turned on one side and used, but the result is generally not at all successful. In land-surveying, military plans of country, or any other kind of topographical drawing, a great use is made of various arbitrary signs, and these must ordinarily be drawn in by hand. Forests, hedgerows, marshes, steep declivities of ground, and many other natural or artificial features, require to be marked. Here, too, practice in free-hand and general pen-and-ink work will be found to be very valuable. The student who would attempt to suggest the idea of a group of trees by means of a ruling-pen and T square would find himself somewhat hampered.

320. All drawings should be signed by the draughtsman, and the year, at least, in which they were done should be added. The nature of the object represented in the drawing would ordinarily be named, as, for instance, "villa residence," "goods locomotive," "punching machine," or "parish of Preshute." Whether plan, elevation, or section should also be stated. If the drawing is a reproduction, the source from which it was derived should be stated.

321. The use of the pen is to some extent aided or super-

seded by the process of stencilling, but the work is rougher in character, and cannot be altogether received as a substitute. Two of its great recommendations are that it ensures uniformity and saves time.

322. The stencil plate is a thin sheet of brass or copper, and in this the letters are perforated. Whole words in common use, such as "elevation" or "section," are often employed; and where many drawings of the same thing are required, or different details that all come under one general head, such as "Great Western Railway," or "Engineer's Office, Metropolitan Board of Works," the two advantages we have named are very evident, as much time is saved, and a desirable uniformity amongst the various drawings is preserved.

323. To use the plate, a brush filled with Indian-ink, or a cheaper preparation made on purpose, is rubbed carefully into the perforations. The colour must not be used in too fluid a state; the plate must be kept firmly pressed down to the surface of the paper, or some of the ink will get beneath the edges of the letters and destroy all their sharpness of form; and great care must be exercised to see that the plate is very firmly held in one position all through. Any slipping or shifting would, if not noticed, spoil the work. By a considerable amount of trouble the plate can be replaced in its proper position, but prevention is in such a case far better than any after remedy.

324. Ornamental borderings and angles, and various accessory devices towards the embellishment of a drawing, may very well be stencilled. To draw the corner designs all alike would entail a deal of trouble; to stencil the four would be a very easy matter. It is impossible to quote any price as a guide to the beginner, as there are so many styles of letters employed, but the cost in any case is slight.

325. As our student probably looks forward to a time when his vaulting ambition will o'erleap any mere outline work, and when colour shall give its added charm, a few words on this point may not be amiss.

326. Colour is ordinarily applied to mathematical drawings in a somewhat conventional way, rather as suggestive of the material than an attempt to express its real tint. The architect expresses brickwork by a tint much paler than that seen in the actual thing, and the engineer gives a much lighter tint to his iron than that of the material itself. Cheap chromo-lithographic things err sadly in the direction of overdoing the colour. They are showy, and may perhaps attract the novice but too generally their meretricious qualities are examples of what to avoid.

327. The colours employed should be good in quality, and only those should be used that admit of transparent washes; care must be taken, too, that the hand should always rest on a piece of waste paper, or the paper will presently refuse to take the colour. "Prevention is better than cure;" but if the greasiness of surface makes itself felt, a little ox-gall added to the colours will cause them to go smoothly on the paper.

328. All colours should be prepared by daylight. They can then be used either for day-work or evening; but colours mixed by artificial light rarely look what we expect when seen in the daytime. Yellow especially should be rubbed by daylight; when it is prepared by the yellow light of oil or gas, it does not look nearly so strong a tint as it really is. A drawing that looks quite satisfactory by artificial light will be many degrees too bright in the white light of day.

329. The tints used by draughtsmen vary somewhat, according to individual fancy, but the following may be

considered a sufficiently reliable guide. Brickwork in plan is ordinarily tinted with crimson lake; and the same colour, with the addition of a little cadmium or yellow-ochre to take the pink look off it, is used for brickwork in elevation. Stone may be put in either with pale grey or pale brown. Woodwork in elevation or plan should be painted in yellow-ochre, and in section the yellow-ochre has the section lines marked on it in burnt sienna. Concrete is expressed by dark grey mottled over irregularly with a stronger tint of the same colour. Slates are marked by washes of either purple or green, the tint in either case being a good deal diluted with water. Iron is indicated by indigo, brass by gamboge, and copper by an orange compounded of gamboge and crimson lake.

330. In plans of estates and building-plots the colours used are those that will best suggest the facts: thus grass is a green composed of gamboge and Prussian blue, water is represented by the blue alone, earth by raw sienna, and so on.

331. One of our best makers of mathematical things has introduced a series of fluid colours adapted for all the purposes of the architect and engineer. Cement, clay, asphalte, concrete, glass, granite, deal, oak, mahogany, slate, tiles, gun metal, lead, zinc, and many other substances, all have their appropriate tint, and such an arrangement possesses many obvious advantages. If, for example, such a set of tints came into general use, this uniformity of colouring for any particular material would at once enable every one to see at a glance what substance was intended. All trouble of mixing tints, too, would be avoided, and there would be no risk of the inconvenience of having to match a tint. As all would be uniform in strength and tint, this particular annoyance, and it is a serious one sometimes, could never occur. Such colours,

to be really useful, should always have the same strength of tint, a perfect solubility and freedom from gritty particles or sediment of any kind, an even flow, a nature that will not injuriously affect any of the instruments with which they may be brought in contact, and a perfect permanence of colour. The maker claims that all these points are carefully observed.

332. Where the ordinary colours are employed, certain simple rules should always be observed. The beginner will often, in making a mixture, rub the second cake of colour into the tint the first has already yielded. In making a green, for example, the yellow may be first rubbed, and the cake of blue is then put into it and rubbed in turn. By this means a good deal of the yellow and resulting green remains on the blue, and makes itself sufficiently, obviously, and disagreeably felt when we take up the cake at another time, either to mix a purple by its aid, or to get a tint of pure blue. The two colours we desire to blend into one should first be mixed in different divisions of the palette or slab, and then worked together by means of the brush.

333. Another failing of beginners is to take the colour off the cake by means of the brush, instead of rubbing it on the slab. This bad habit makes a hole in the middle of the cake and splits it up, and is very injurious, moreover, to the brushes. Even the mere rubbing on the slab may be properly or wrongly done. We sometimes see the cake dipped to half its length in the cup of water before being rubbed, and this procedure guarantees a very speedy cracking and crumbling of the cake. The orthodox way of going to work is to take a very few drops of water, either by means of the finger or brush, put them on the slab, and then proceed to rub the colour. After rubbing colours or the Indian-ink they should be put carefully aside, and the wet ends tilted up against a

pencil or the edge of the slab, or they will soil the table, and then the set-square or scale may transfer the spot to the work.

334. As some colours are naturally heavier than others, the brush should be dipped thoroughly into any tint that has been compounded, and at every few dippings the whole should be thoroughly well stirred, so as to prevent any sediment being deposited. If our readers will compound an orange tint of vermilion and gamboge, and then let it stand aside for an hour or so, they will see that it continues to grow yellower and yellower in appearance as the heavier ingredient, the vermilion, sinks to the bottom; and just this same effect would be created on the drawing if the stirring process were neglected during its application.

335. The slab of colour should be placed conveniently near to the right hand, and any colour that has to be transferred from one side to the other should not be passed over the drawing.

336. The brushes should be of two or three different sizes, so as to be adapted to the varying nature of the work. Fine work cannot very well be done with a coarse brush, and, on the other hand, a fine brush would be useless for laying a large wash of colour. A man of experience in the work has such a mastery over his tools that he will often use one favourite brush almost all through a drawing, but the beginner will certainly find it an advantage to him to have several sizes, and to employ them with a due regard to the conditions of the work.

337. When a brush is not in use it should be carefully washed and put aside. It is a terrible hindrance to good work, and very destructive to the brushes themselves, to put them away dirty, to reappear harsh and clogged with paint. Even when temporarily laid aside during the pro-

gress of the work they should always be cleansed, or a brush laden with blue or yellow is suddenly dipped into the crimson tint, to the great damage probably of both tint and temper.

338. In selecting a brush, it should be dipped slightly in water or moistened between the lips. If it forms a good point, and maintains its elasticity when gently pressed on the thumb-nail, it will probably prove serviceable; but if it persists in forming two or three separate points, or keeps any bend into which it is placed, then the sooner it is discarded the better. Brushes should be renewed from time to time, as it is really very poor economy to work with them when they grow stumpy and ragged.

339. The brushes ordinarily employed in all water-colour work are either made of camel-hair or of sable. The sables are of two kinds, the red and the brown. Some authorities tell us that the brown sable brushes are much the better, while others hold that there is little difference really in their quality. The red sables are much the cheaper, and our advice to our readers would certainly be to buy those until the disputed point be settled, and, indeed, afterwards too, for the red, in our opinion, answers all the necessary requirements as thoroughly as one could wish. Camel-hair is much cheaper than either kind of sable; it has not, however, the wear nor the elasticity in it of the others, and is chiefly used in the large brushes used for laying extensive surfaces of colours. Sable brushes of the necessary size for this work would be very costly, and for this purpose the camel-hair is quite good enough.

340. The sizes known to the trade as large swan-quill, goose-quill, and duck-quill would be very useful sables to get. The first would cost about 5s. or 3s., according to whether we selected brown sable or red; the second would be

either about 10d. or 7d., and the third would be perhaps 6d. or 5d. When we get to larger sizes the prices increase a good deal, but a good camel-hair brush for large washes, a flat brush having the hair two inches wide, would only cost a shilling.

341. Any directions as to the actual methods of tinting and shading, the leaving or picking out of lights, the management of reflected light, stippling, sponging, &c., would, to be worth anything at all, entail a far larger amount of space than their subordinate position in a manual on mathematical instruments would justify. We must content ourselves with the broad outline of the subject, and refer our readers to other works for this special information, or, better still, advise them, if possible, to see some practised hand actually at work.

342. In the hope that the details we have been able to give and the points of practical importance we have brought forward may prove of use to the beginner and save him much needless trouble, we commend our labours to our readers. Many of the points may appear trivial and self-evident, but every one has to make his own beginning, and facts that have long grown into truisms to the experienced hand are perplexing novelties to the novice. We can only hope, in conclusion, that our explanations and suggestions may prove as helpful to the student as it has been our sincere desire to make them.

PRINTED BY BALLANTYNE, HANSON AND CO.
EDINBURGH AND LONDON